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CREEP OF CARBON FIBRE REINFORCED PLASTICS

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SUMMARY

Creep tests have been performed on unidirectional 0°, cross-plied 0 + 90°, angle-plied ±45° and multi-plied 0 ± 45° and 90 ± 45° carbon fibre reinforced plastics. The test temperatures were 21°C and 80°C except for ±45° orientations where the upper temperature was 50°C.

Small creep strains were observed in 0°, 0 + 90° and 0 ± 45° materials after 1000 hours at stresses of 40% and 80% of the tensile strength. The creep resistance of 90 ± 45° composite was lower than material containing 0° fibres but higher than simple ±45° constructions.

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CONTENTS

1 INTRODUCTION

The original impetus behind the development of carbon fibres was the prospect of light stiff fibres to reinforce plastics materials which could be used in highly stressed applications without suffering excessive deflections. Monotonic testing of CFRP (carbon fibre reinforced plastics) established the potential of the material[1] but creep tests were required to determine the response to sustained loadings.

A limited amount of creep data has been published for CFRP tested in flexure[2] and on small specially prepared tensile specimens[3]. Some 10 second creep compliance tests have also been made on unidirectional 0° and angle-plied $\pm 15^\circ$, $\pm 30^\circ$ and $\pm 45^\circ$ material[4]. Few data are available for material systems of interest in structural applications. Accordingly a small programme has been conducted on such materials, made by commercial laminating processes.

The data presented in this Report form the first three phases of a continuing creep programme and illustrate the behaviour of CFRP laminates with fibre orientations of 0°, $\pm 45^\circ$, $0 + 90^\circ$, $0 \pm 45^\circ$ and $90 \pm 45^\circ$. Some data for material with $\pm 45^\circ$ orientations have already been published[5] but are included here for completeness.

2 MATERIALS

When this investigation began the epoxy resin system of most interest for use, in the British aircraft industry, as a matrix for CFRP was ERLA 4617 (Union Carbide-Bakelite). Thus the early work was performed using this cyclo-aliphatic epoxy system. Subsequently it was withdrawn from the market and in later parts of the programme the bisphenol-A based epoxy system DX210 (Shell Chemical Co.) was used instead.

The fibre type used throughout was surface treated high strength type 2. The composites can be conveniently grouped under three headings which indicate the laminating technique used in each case:-

(1) Unidirectional 0° CFRP with matrix resin ERLA 4617, curing agent diamino diphenylmethane (DDM).

(2) Cross-plied $0 + 90^\circ$ CFRP with matrix resin ERLA 4617, curing agent DDM.

(3) Angle- and multi-plied $\pm 45^\circ$, $0 \pm 45^\circ$ and $90 \pm 45^\circ$ CFRP with matrix resin DX210, curing agent $BF_3 400$ boron trifluoride amino complex.

The laminating techniques were as follows:

(i) Material 1. A single laminate, from which all the specimens were taken, was made in a matched metal mould. Sheets of preimpregnated fibres (prepreg),

supplied by Fothergill and Harvey Ltd., were loaded into a cold mould which was then placed in a press with its platens at room temperature. The mould temperature was raised slowly to 130°C over 1 hour and pressure applied 15 minutes after attaining 130°C. Stops were used to close the mould forces to the correct laminate thickness and the temperature was held at 130°C for 5 hours. Finally a post-cure was given in the press for 18 hours at 170°C.

(ii) Material 2. Two laminates were made of this material. The matched metal mould was charged with eight layers of prepreg at orientations of 0°, 90°, 0°, 90°, 90°, 0°, 90°, 0°. It was then transferred to a press with platens which had been preheated to 135°C. The mould temperature was raised to 125°C over a period of 75 minutes after which the mould forces were closed to stops. The laminates were cured for 2 hours at 130°C followed by a post-cure in an air circulating oven for 16 hours at 170°C.

(iii) Material 3. Two laminates were made in an autoclave. The 0 ± 45° and 90 ± 45° specimens were taken from the same laminate. Its construction was 0°, +45°, -45°, 0°, 0°, -45°, +45°, 0°. The ±45° test-pieces had the following ply pattern +45°, -45°, +45°, -45°, -45°, +45°, -45°, +45°. Details of the laminating technique have already been given elsewhere[5].

The nominal thickness of material 1 composite was 2.5mm. All the other materials had a nominal thickness of 2mm. All materials were prepared to a fibre volume fraction of 60%.

3 CREEP TEST SPECIMENS AND TESTING TECHNIQUES

3.1 Creep test specimens

The design of a tensile test specimen for use with unidirectional CFRP has been described by Ewins[6]. This takes account of the low shear strength and high tensile strength of the material. The specimen is waisted through the thickness, not the width, and has parallel sides. This basic design was also chosen for creep testing because earlier attempts with long dumb-bell specimens had failed to achieve the estimated material strength.

The unidirectional 0° creep specimen is shown in Fig.1. The long parallel waist was machined with a diamond impregnated wheel. Aluminium alloy pads were bonded to the specimen to protect the composite from the extensometer points. The reduced thickness at the waist was 1.5mm and the extensometer gauge length was 50mm.

Load was applied to the CFRP portion of the test-piece through aluminium plates which were bonded to the ends, Fig.2. The holes take the creep machine attachment pins. To reduce the possibility of glue-line shear failure during sustained loadings bolted clamps were placed at the overlap of the CFRP and aluminium end-plates. The unsupported length was 140mm.

Thickness waisted specimens cannot be used for cross-, angle- or multi-plied materials. Instead a width waisted specimen was used for $0 + 90^{\circ}$ cross-plied specimens, Fig.3, and a plain rectangular specimen for angle- and multi-plied laminates, Fig.4. In both cases end-plates were bonded to the specimen but though these were similar to those in Fig.2 they had a wider stem to accommodate the broader specimen. Clamps were also fitted to prevent glue-line failures and the unsupported length was again 140mm.

3.2 Testing techniques

Creep and monotonic tensile tests were made in Denison 50kN creep machines. Where possible the creep tests conformed to British Standard 3500, part 3.

Creep tests at both $21^{\circ}C$ and $80^{\circ}C$ were carried out on 0°, $0 + 90^{\circ}$, $0 \pm 45^{\circ}$ and $90 \pm 45^{\circ}$ specimens. Angle-plied $\pm 45^{\circ}$ specimens were tested at $21^{\circ}C$ and $50^{\circ}C$.

Strain was measured on both sides of the 50mm gauge length portion of the test-piece using conventional rollers/mirror extensometers attached to the rectangular aluminium pads by screw points. The sensitivity of the extensometers was approximately 0.0002% strain.

The air temperature of the creep test laboratory was controlled at $21^{\circ}C \pm 1.5^{\circ}C$ but no attempt was made to control humidity. During elevated temperature testing both the temperature and temperature variation along the gauge length were monitored with platinum/platinum 13% rhodium thermocouples. In general the surface temperature at the centre of a test-piece was controlled to about $\pm 1.5^{\circ}C$ with a maximum variation along the gauge length of $1.0^{\circ}C$.

A standard procedure was adopted for heating the elevated temperature test-pieces. The test temperature, less about 5%, was attained in approximately 4 hours. Close control of temperature and temperature variation along the specimen was established during a 24 hour soak. Load was then applied incrementally. During this loading the elastic modulus was determined, except in the case of $\pm 45^{\circ}$ material. Here the initial creep rates were extremely high, particularly at elevated temperatures, thus no accurate estimate of elastic strain could be made.

The tensile strengths of unidirectional 0° and cross-plied 0 + 90° composites were determined at 21°C in the Denison creep machines. Constant stresses equivalent to approximately 40% and 80% of this 21°C tensile strength were used in creep tests at both 21°C and 80°C.

The strength of angle-plied ±45° material was determined in a Mayes servo-hydraulic testing machine during the course of a fatigue programme on the same material. The tests were made at 21°C*.

Stress-rupture failures were anticipated with ±45° material during sustained loading so relatively low values of stress were applied to creep specimens. Expressed as a percentage these stresses were 31%, 46.5% and 62% of the room temperature tensile strength. No stress-rupture failure occurred even at 50°C and a stress of 62% of the tensile strength.

Although monotonic failure tests had been made at room temperature and successful creep tests had been performed up to 80% of the tensile strength and 80°C for 0° and 0 + 90° materials, it was felt that a similar testing schedule might not be suitable for 0 ± 45° and 90 ± 45° composite. Instead the strength was determined at 80°C and creep stresses of 40% and 80% of this value were used for creep tests at 80°C and 21°C. This avoided any problems which might have occurred had there been a significant strength loss at the elevated temperature. Also the resin system DX210/$F_3$400 is not suitable for high temperature use and stress-rupture of the 90 ± 45° material may have occurred at 80°C if the stress levels had been set too high.

Lastly, it should be noted that all the stress levels were chosen arbitrarily. They do not represent typical service loading conditions for, as yet, it is not clear to what percentage of ultimate strength carbon fibre composites will be used in structural applications.

4 MONOTONIC AND TENSILE CREEP TEST RESULTS

The results of monotonic tests to measure both elastic modulus and tensile strength of 0°, 0 + 90°, 0 ± 45° and 90 ± 45° laminations are given in Tables 1 to 4. The data for tensile strength tests on ±45° material are given in Table 5.

Individual items of creep data have not been given but summaries of the 1000 hour creep test results appear in Tables 6 to 10. Curves of creep strain

* The specimen used for tensile testing was not identical with the creep specimen, its length to width ratio was smaller. Overall the length of the tensile specimen was 250mm, end plates were bonded to each end leaving a free unsupported length of 170mm. The width was 40mm and the thickness 2mm. Further details are given in Ref.5.

with log (time) are shown in Figs.5 to 25. A summary of the creep test programme and the appropriate creep curves is given below.

Laminate construction	Creep test temperature °C	Creep stress level MPa	Creep stress as a percentage of tensile strength at temperature (in brackets)	Figure number of the relevant creep curve
0°	21	529	40% (21°C)	5
0°	21	1058	80% (21°C)	6
0°	80	529	40% (21°C)	7
0°	80	1058	80% (21°C)	8
$0 + 90^{\circ}$	21	220	40% (21°C)	9
$0 + 90^{\circ}$	21	400	73% (21°C)	10
$0 + 90^{\circ}$	80	220	40% (21°C)	11
$0 + 90^{\circ}$	80	400	73% (21°C)	12
$0 \pm 45^{\circ}$	21	320	40% (80°C)	13
$0 \pm 45^{\circ}$	21	640	80% (80°C)	14
$0 \pm 45^{\circ}$	80	320	40% (80°C)	15
$0 \pm 45^{\circ}$	80	640	80% (80°C)	16
$90 \pm 45^{\circ}$	21	62	40% (80°C)	17
$90 \pm 45^{\circ}$	21	125	80% (80°C)	18
$90 \pm 45^{\circ}$	80	62	40% (80°C)	19 a and b
$90 \pm 45^{\circ}$	80	125	80% (80°C)	20
$\pm 45^{\circ}$	21	50	31% (21°C)	21
$\pm 45^{\circ}$	21	75	46.5% (21°C)	22
$\pm 45^{\circ}$	21	100	62% (21°C)	23
$\pm 45^{\circ}$	50	75	46.5% (21°C)	24
$\pm 45^{\circ}$	50	100	62% (21°C)	25

5 DISCUSSION

5.1 Composites containing 0° fibres

The most satisfactory way of comparing the three materials which contain 0° fibres is to consider not the actual stresses applied over the whole cross-section but rather the stresses in the 0° fibres alone. Thus the stress levels quoted in Tables 7 and 8, for $0 + 90^{\circ}$ and $0 \pm 45^{\circ}$ material respectively, should be doubled to give an estimate of the stresses in the 0° fibres. The stresses in 0° fibres in each of the three constructions are thus of the same order and the creep strains given in Tables 6, 7 and 8 can be compared. It is also clear that creep effects in these constructions are small up to the 1000 hour time limit of the data.

The creep strain of unidirectional 0° and cross-plied $0 + 90^{\circ}$ material appears to be a characteristic of the laminate construction as there is almost no dependence on either stress level or temperature. Unidirectional material exhibits the greater resistance to creep showing strains at 1000 hours in the range 0.004 to 0.009%. In $0 + 90^{\circ}$ composite the strains are twice as large being between 0.010 and 0.018%. The reason for this is discussed later.

Multi-plied $0 \pm 45^{\circ}$ laminates behave slightly differently from the other two constructions. The 0° fibre stresses in the $0 + 90^{\circ}$ and $0 \pm 45^{\circ}$ are similar when both are loaded to 40% and 80% of their tensile strengths. Thus, once again, the creep strains can be compared. At 40% of the tensile strength the creep strains were similar for both materials. When loaded to 80% of their strength the $0 \pm 45^{\circ}$ construction showed strains of 0.022 to 0.033% which were a little larger than the range of 0.010 to 0.018% of the $0 + 90^{\circ}$ composite. Furthermore at this higher stress level there appeared to be a very slight temperature dependence with $0 \pm 45^{\circ}$ material. At $21^{\circ}C$ the creep strain caused by a stress of 80% of the tensile strength was about 0.024% compared with 0.029% at $80^{\circ}C$.

5.2 Multi-plied $90 \pm 45^{\circ}$ material

Laminates with $90 \pm 45^{\circ}$ fibre orientations are much more dependent on the properties of the matrix than constructions containing 0° fibres. Thus it would be expected that such materials would behave in a similar manner to polymeric materials. Considered in this light the response of $90 \pm 45^{\circ}$ construction is somewhat anomalous. A polymeric solid would be expected to show

creep strains which were dependent on both stress and temperature. A temperature effect was observed at 40% of the tensile strength where the 21°C strain was 0.033% compared with 0.053% at 80°C.

At 80% of the tensile strength there is no significant temperature dependence of creep strain. The 21°C 1000 hour creep strain is 0.183% which is similar to, but somewhat surprisingly, slightly larger than the 80°C value of 0.167%. It will be interesting to see whether these results are confirmed by further work on this and other resin systems.

5.3 Angle-plied ±45° material

Angle-plied ±45° composite is similar to 90 ± 45° material in that the resin matrix carries a considerable portion of any applied load. It too can therefore be expected to behave more like a polymeric material and this was indeed found to be the case. Creep strains were dependent on both stress and temperature increasing with an increase in either, or both, of these parameters.

5.4 The influence of laminate construction on the creep of CFRP

The increasing creep strain, at constant 0° fibre stress, on changing from 0° to 0 + 90° and then to 0 ± 45° CFRP is interesting. It indicates that even under tensile loadings laminate construction may well influence creep*.

In multi-directional constructions part of the time dependent extension may be the result of locally misaligned fibres straightening under the influence of an applied load. Indeed direct observation of fibre straightening during creep has been made by Dobson who used specially prepared unidirectional test-pieces[3]. Local misorientation can occur in multi-plied laminates because fibres at one orientation are effectively laminated against a substrate which is both flexible and slightly corrugated. The flexibility is caused by the low resin viscosity which results when the temperature is raised during the laminating process before cross-linking has advanced appreciably. Corrugations are due to individual tows in the prepreg which tend to be slightly thicker in their centres than at their edges. As a consequence fibres in multi-plied material are unlikely to be quite as straight as in unidirectional laminates, and therefore as the fibres straighten a larger extension can be expected.

* It is, of course, anticipated that laminate construction will influence the observed creep strain in other modes of loading such as flexure, shear and compression where the stress distribution is more complex than simple tensile loading. These other modes of loading are outside the scope of this Report.

A striking example of the influence of laminate construction on creep behaviour emerges from comparing ±45° and 90 ± 45° materials. Both have similar strengths, namely 161MPa and 154MPa respectively. The introduction of 90° laminations therefore has little effect on load carrying capacity but, as the data of Tables 9 and 10 show, their influence on creep resistance is enormous. Transverse 90° laminae reduce the creep strains by approximately one order of magnitude. An explanation for this may be the following: ±45° material can deform by a combination of tensile creep in the 0° direction, shearing creep along planes normal to fibre axes and rotation of the plies towards the 0° loading axis; the addition of 90° laminae prevents rotation of ±45° plies and reduces the tendency to shear, leaving only the tensile creep component which is relatively small.

5.5 The relationship between creep strain and time under load in carbon fibre composites

The creep curves show that 0°, 0 + 90° and 0 ± 45° materials give essentially linear relations between creep strain and log (time) up to 1000 hours of loading. The exception is 0 ± 45° composite tested at 80°C where a plateau tends to be established between 10 and 100 hours.

In the case of 90 ± 45° and ±45° materials there is no sign of a plateau after 1000 hours during room temperature tests. The creep curves are not linear but seem to consist of two portions which are themselves nearly linear. At 80°C, 90 ± 45° constructions exhibited plateaux on the creep curves at times within the range of 10 to 1000 hours. Similar behaviour was found with ±45° material tested at 50°C.

6 CONCLUSIONS

(1) Creep strains are small being less than 0.034% in 0°, 0 + 90° and 0 ± 45° orientations of CFRP tested for 1000 hours at 21°C or 80°C, and stresses up to 80% of the short time tensile strength.

(2) The creep strain increases on changing the laminate construction from unidirectional 0° to cross-plied 0 + 90° to multi-plied 0 ± 45° CFRP. For sustained loadings at both 21°C and 80°C at 40% and 80% of the tensile strengths the ratio of their creep strains for fibre volume fractions of 60% is, very approximately, 1:2:3 respectively.

(3) Creep in 0° and 0 + 90° CFRP is almost independent of stress and temperature within the range studied. Multi-plied 0 ± 45° material did show a slight increase in creep strain with increases in temperature and stresses.

(4) Angle-plied $\pm 45^{\circ}$ composite behaved like a typical polymeric material. Creep strain was dependent on both temperature and stress, increasing with increases in either parameter.

(5) The behaviour of $90 \pm 45^{\circ}$ CFRP was different from the other orientations. At low stresses an increase in temperature increased the creep strain but at high stress levels there appeared to be no dependence of creep on temperature.

(6) The influence of additional ply orientations on the creep behaviour of $\pm 45^{\circ}$ material was considerable. Adding 90° laminae to give a $90 \pm 45^{\circ}$ construction reduced the creep strains at 1000 hours by about an order of magnitude. Addition of 0° fibres to make $0 \pm 45^{\circ}$ composite gave a reduction of approximately two orders of magnitude.

Table 1

TENSILE TESTS ON UNIDIRECTIONAL 0° CFRP AT $21^{\circ}C$

Fibre, Type 2 treated. Resin, ERLA 4617

Specimen number	Tensile strength MPa	Elastic modulus GPa
1	1340	157.9
2	1287	164.1
3	1340	147.6
	Average 1322	Average 156.5

Table 2

TENSILE TESTS ON CROSS-PLIED 0 + 90° CFRP AT $21^{\circ}C$

Fibre, Type 2 treated. Resin, ERLA 4617

Specimen number	Tensile strength MPa	Elastic modulus GPa
174/1	547	76
174/5	534	80
169/1	528	80.7
169/2	571	74.4
	Average 545	Average 77.8

Table 3

MODULUS AND TENSILE STRENGTH TESTS ON MULTI-PLIED 0 ± 45° CFRP AT 21° AND 80°C

Fibre, Type 2 treated. Resin, DX210

Specimen number	Test temperature °C	Tensile strength MPa	Elastic modulus GPa
SA 23/1	21	-	85.4
	80	770	85.0
SA 23/2	21	-	88.9
	80	822	94.1
SA 23/3	21	-	94.1
	80	782	92.4
		Average 791	Average at 21°C 89.3
			Average at 80°C 90.5

Table 4

TENSILE TESTS ON MULTI-PLIED 90 ± 45° CFRP AT 80°C

Fibre, Type 2 treated. Resin, DX210

Specimen number	Test temperature °C	Tensile strength MPa	Elastic modulus GPa
SA 23/1X	80	138.4	19.2
SA 23/5X	80	160.0	Not available
SA 23/6X	80	150.0	21.1
SA 23/10X	80	167	20.4
		Average 153.75	Average 20.2

Table 5

TENSILE TESTS ON ANGLE-PLIED ±45° CFRP AT 21°C

Fibre, Type 2 treated. Resin, DX210

Specimen number	Tensile strength MPa
SA 37/9	167
SA 37/18	156
SA 37/27	161
SA 38/9	170
SA 38/18	161
SA 38/27	153
	Average 161

Table 6

SUMMARY OF CREEP TEST RESULTS FOR UNIDIRECTIONAL 0° CFRP

Test piece number	Test temperature °C	Creep stress MPa	Elastic modulus on loading GPa	Strain on loading %	Creep strain after 1000 hours %
492	21	529	144	0.304	0.006
494A	21	529	151	0.291	0.008
494	21	1058	153	0.647	0.009
495	21	1058	144	0.649	0.006
B493	80	529	150	0.330	0.0045
B500	80	529	150	0.320	0.004
B495	80	1058	147	0.644	0.005

Table 7

SUMMARY OF CREEP TEST RESULTS FOR CROSS-PLIED 0 + 90° CFRP

Test piece number	Test temperature °C	Creep stress MPa	Elastic modulus on loading GPa	Strain on loading %	Creep strain after 1000 hours %
169/3	21	220	84.8	0.210	0.0120
169/4	21	220	79.3	0.230	0.0176
174/3	21	400	80.9	0.462	0.0169
174/7	21	400	72.0	0.503	0.0120
169/5	80	220	73.3	0.250	0.0103
169/8	80	220	79.4	0.220	0.0120
174/6	80	400	72.6	0.499	0.0134
174/8	80	400	85.8	0.415	0.0147

Table 8

SUMMARY OF CREEP TEST RESULTS FOR MULTI-PLIED 0 ± 45° CFRP

Test piece number	Test temperature °C	Creep stress MPa	Elastic modulus on loading GPa	Strain on loading %	Creep strain after 1000 hours %
SA 23/5	21	320	86.2	0.321	0.0139
SA 23/11	21	320	90.0	0.310	0.0176
SA 23/8	21	640	87.3	0.682	0.0224
SA 23/12	21	640	91.8	0.632	0.0251
SA 23/6	80	320	87.0	0.318	0.0187
SA 23/9	80	320	89.2	0.309	0.0124
SA 23/7	80	640	83.4	0.722	0.0252
SA 23/10	80	640	85.4	0.702	0.0334

Table 9

SUMMARY OF CREEP TEST RESULTS FOR MULTI-PLIED 90 ± 45° CFRP

Test piece number	Test temperature °C	Creep stress MPa	Elastic modulus on loading GPa	Strain on loading %	Creep strain after 1000 hours %
SA 23/13X	21	62	23.3	0.175	0.034
SA 23/14X	21	62	23.4	0.175	0.032
SA 23/11X	21	125	23.9	0.493	0.170
SA 23/12X	21	125	23.3	0.494	0.196
SA 23/2X	80	62	19.9	0.204	0.064
SA 23/7X	80	62	20.5	0.199	0.042
SA 23/3X	80	125	20.8	0.521	0.170
SA 23/4X	80	125	21.1	0.511	0.165

Table 10

SUMMARY OF CREEP TEST RESULTS FOR ANGLE-PLIED ±45° CFRP

Test piece number	Test temperature °C	Creep stress MPa	Strain on loading %	Creep strain after 1000 hours %
SA 39/6	21	50	0.19	0.194
SA 39/2	21	75	0.362	0.517
SA 39/8	21	100	0.701	0.773
SA 39/4	50	75	0.458	1.003
SA 39/7	50	100	~2.0*	1.175

* The creep rate in this specimen was initially very high and an accurate assessment of the elastic strain on loading was impossible.

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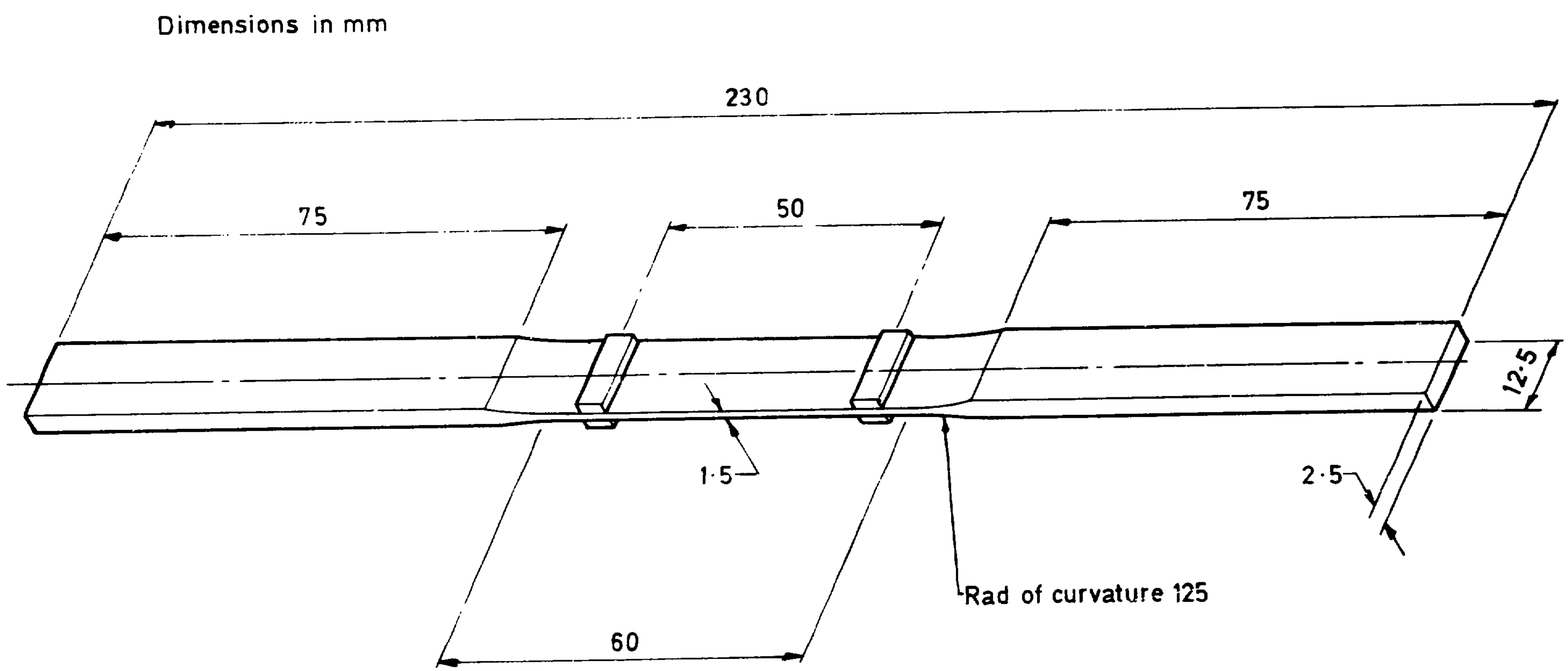

Fig.1 Unidirectional 0° CFRP creep specimen

Fig.2

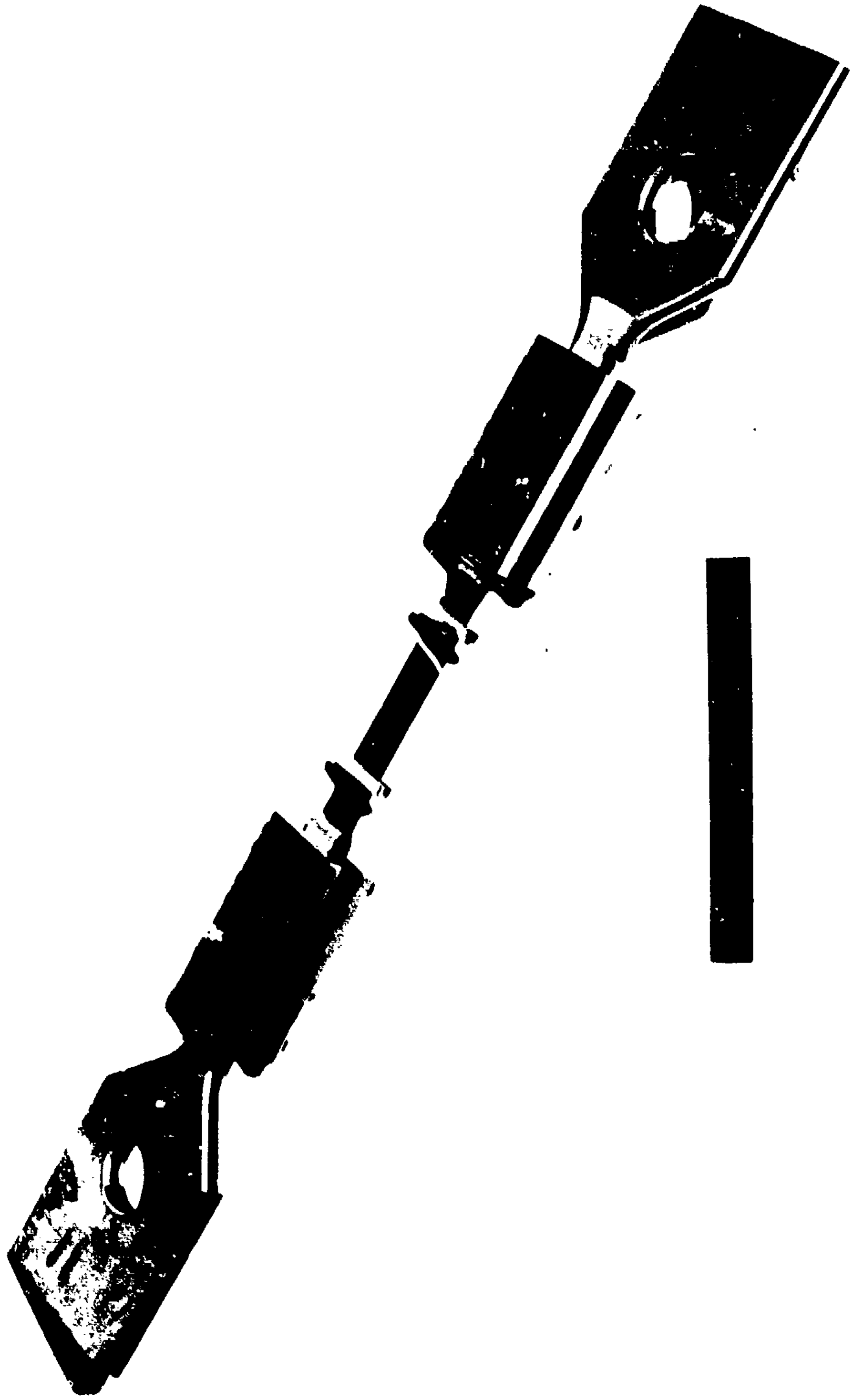

Fig.2 Tensile creep specimen

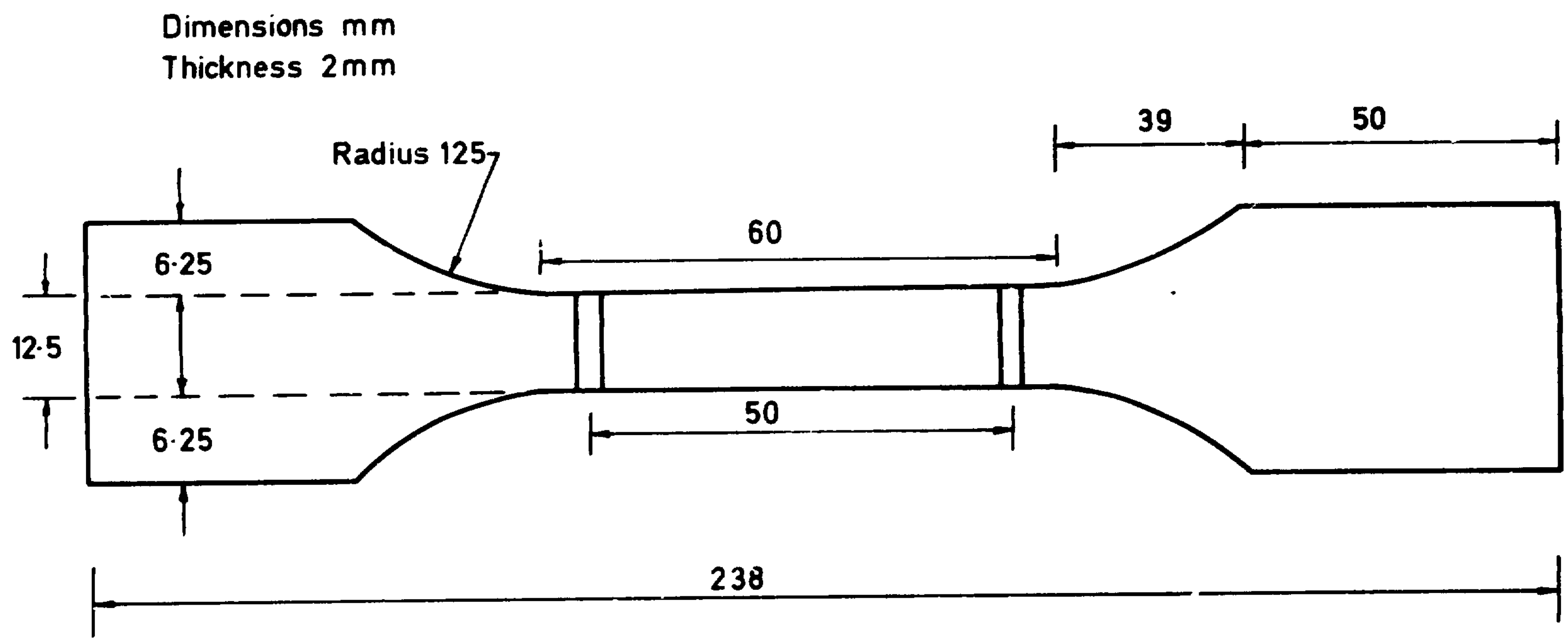

Fig.3 Cross-plied 0+90° CFRP creep specimen

Dimensions in mm

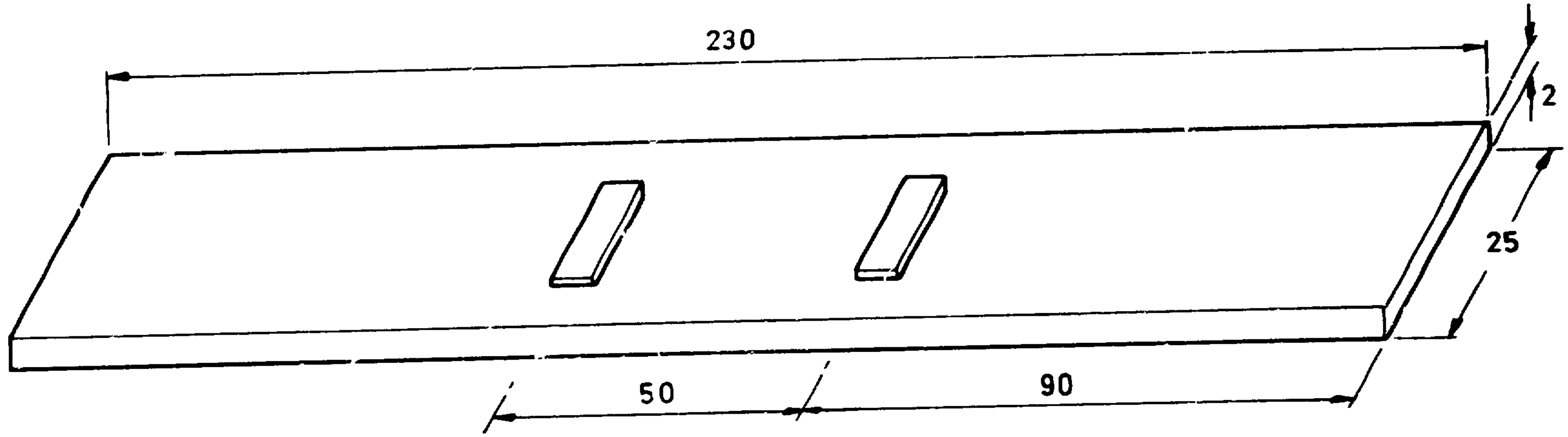

Fig. 4 CFRP creep specimen for 0±45°, 90±45° and ±45° laminate constructions

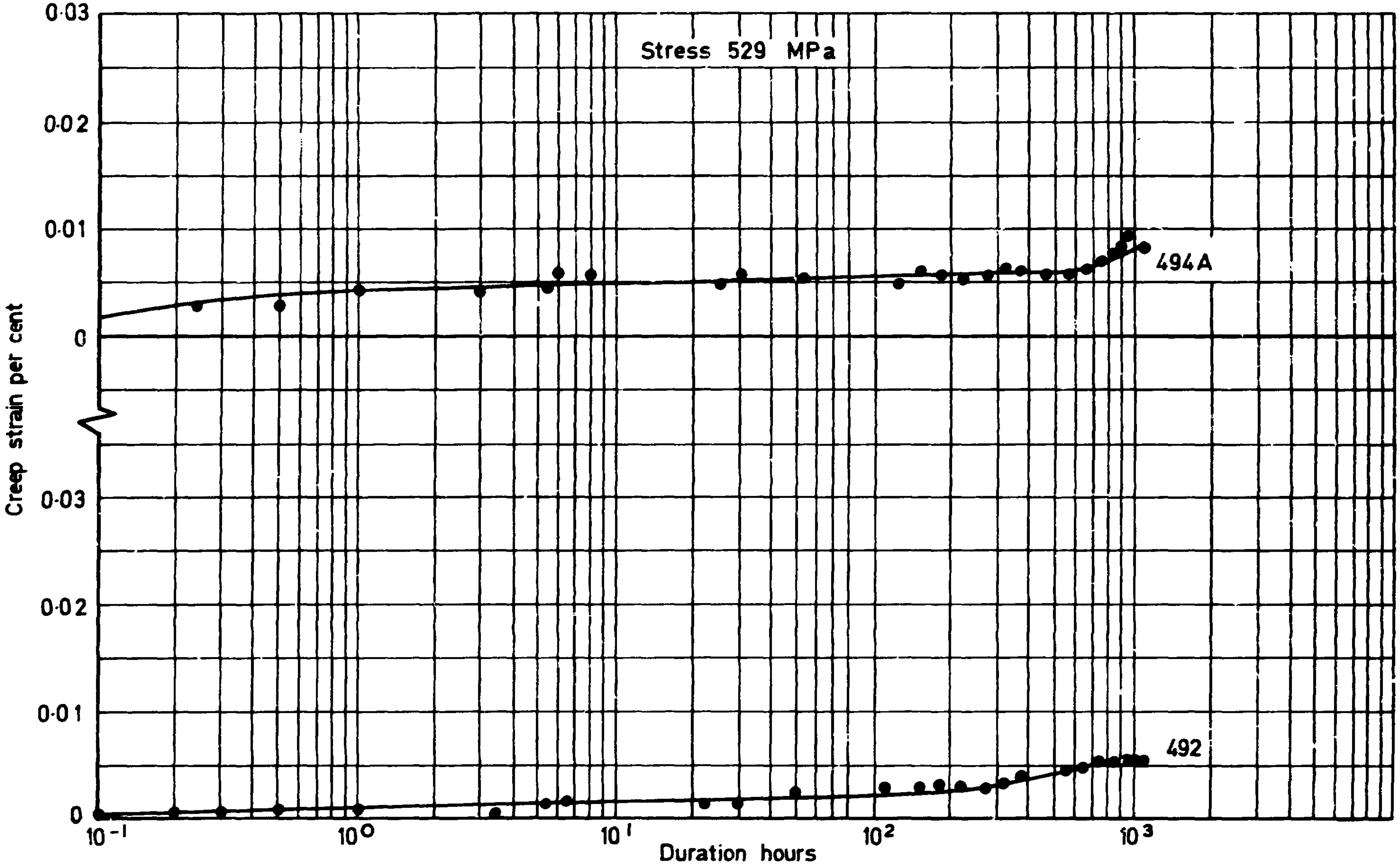

Fig. 5 Results of creep tests at 21°C on unidirectional 0° CFRP

Fig. 5

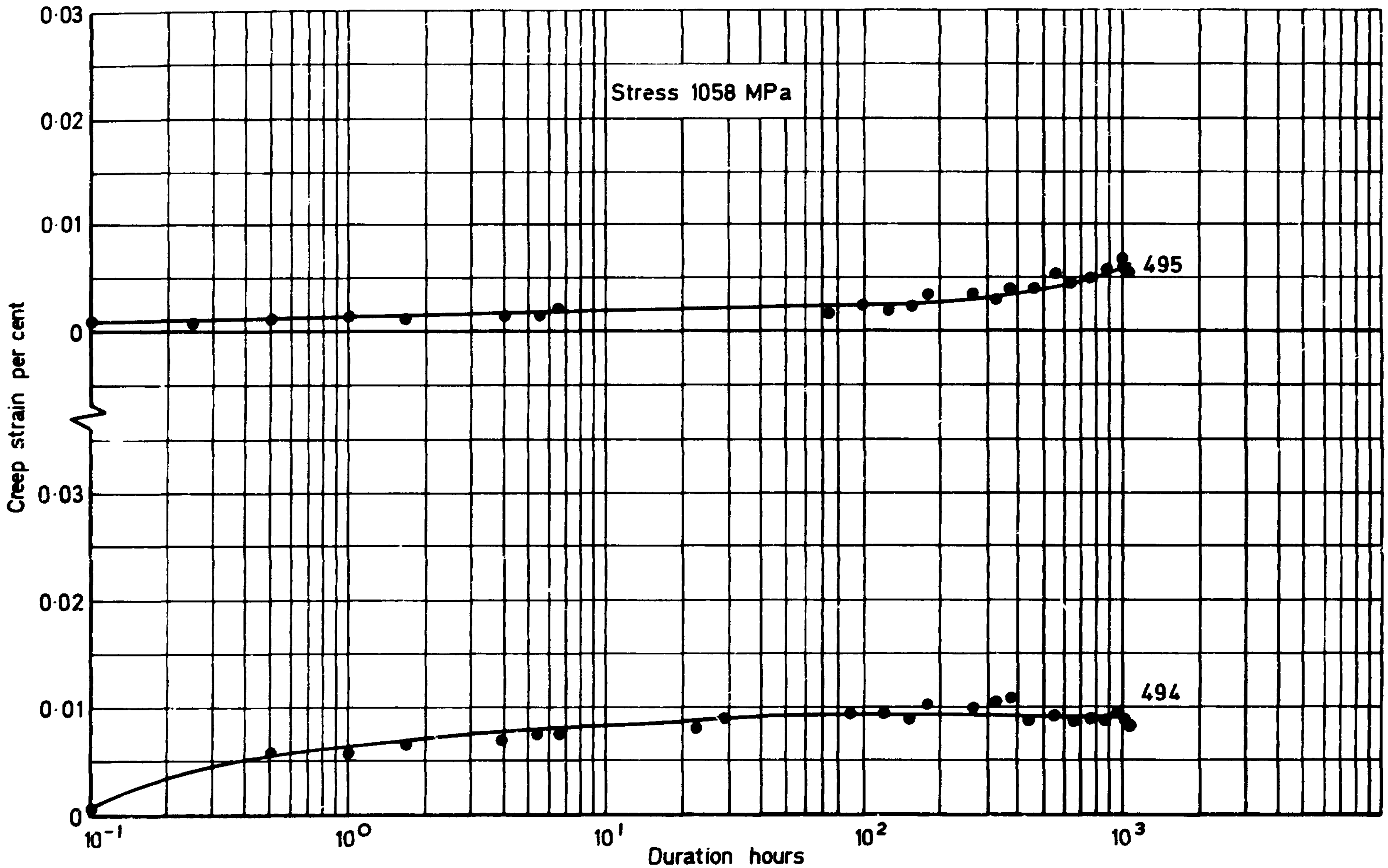

Fig. 6 Results of creep tests at 21°C on unidirectional 0° CFRP

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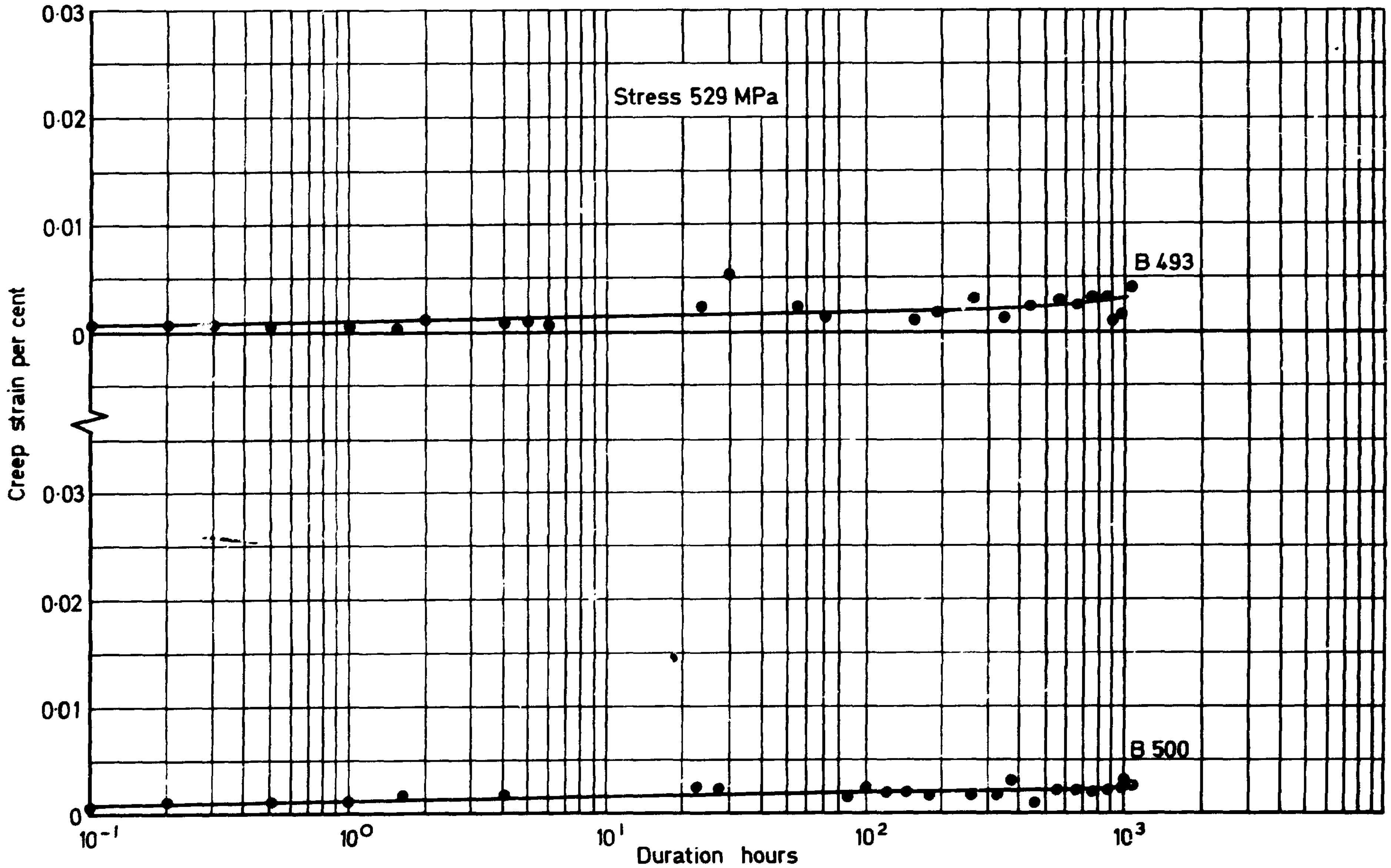

Fig. 7 Results of creep tests at 80 °C on unidirectional 0° CFRP

Fig. 8

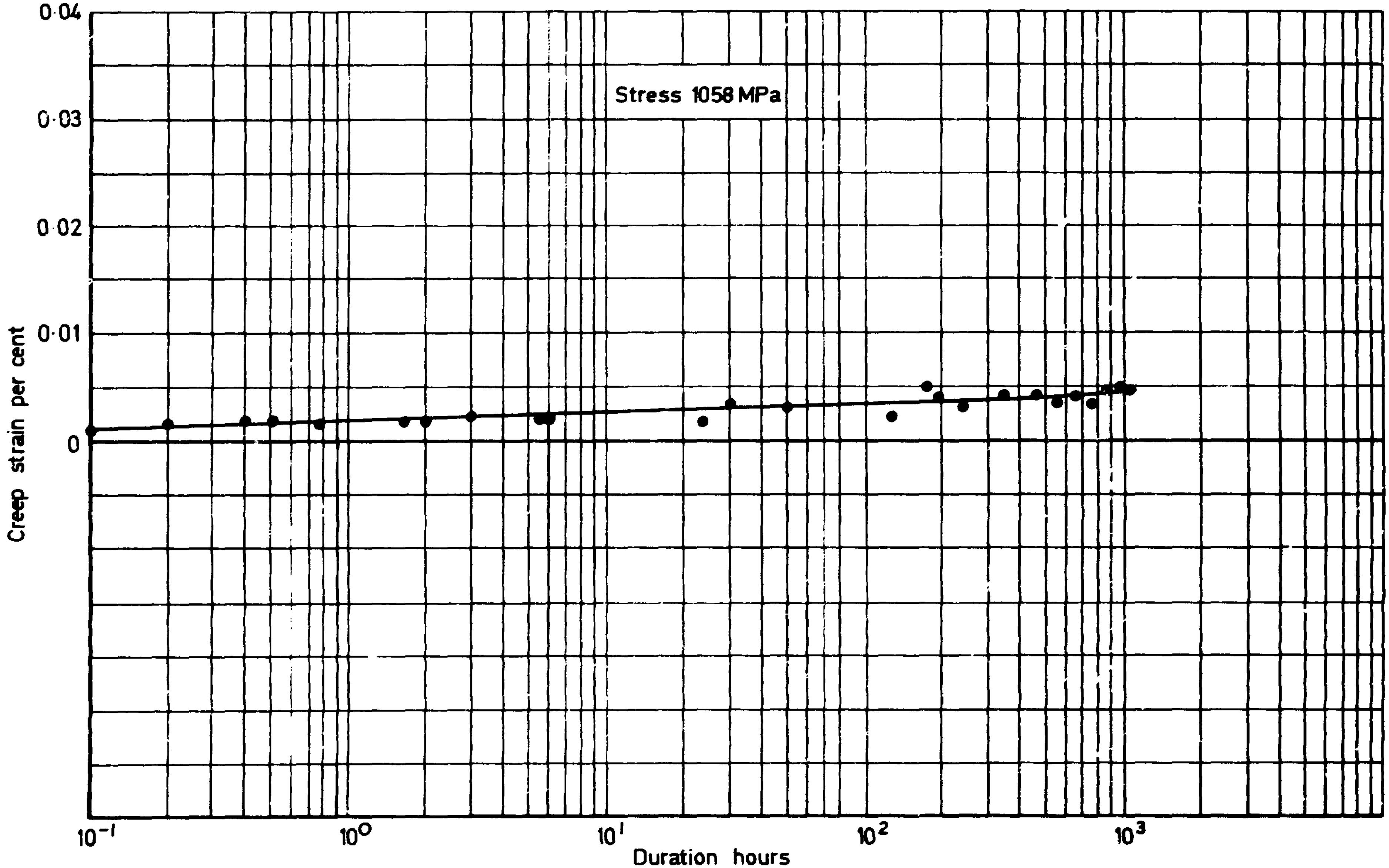

Fig. 8 Results of creep tests at 80°C on unidirectional 0° creep

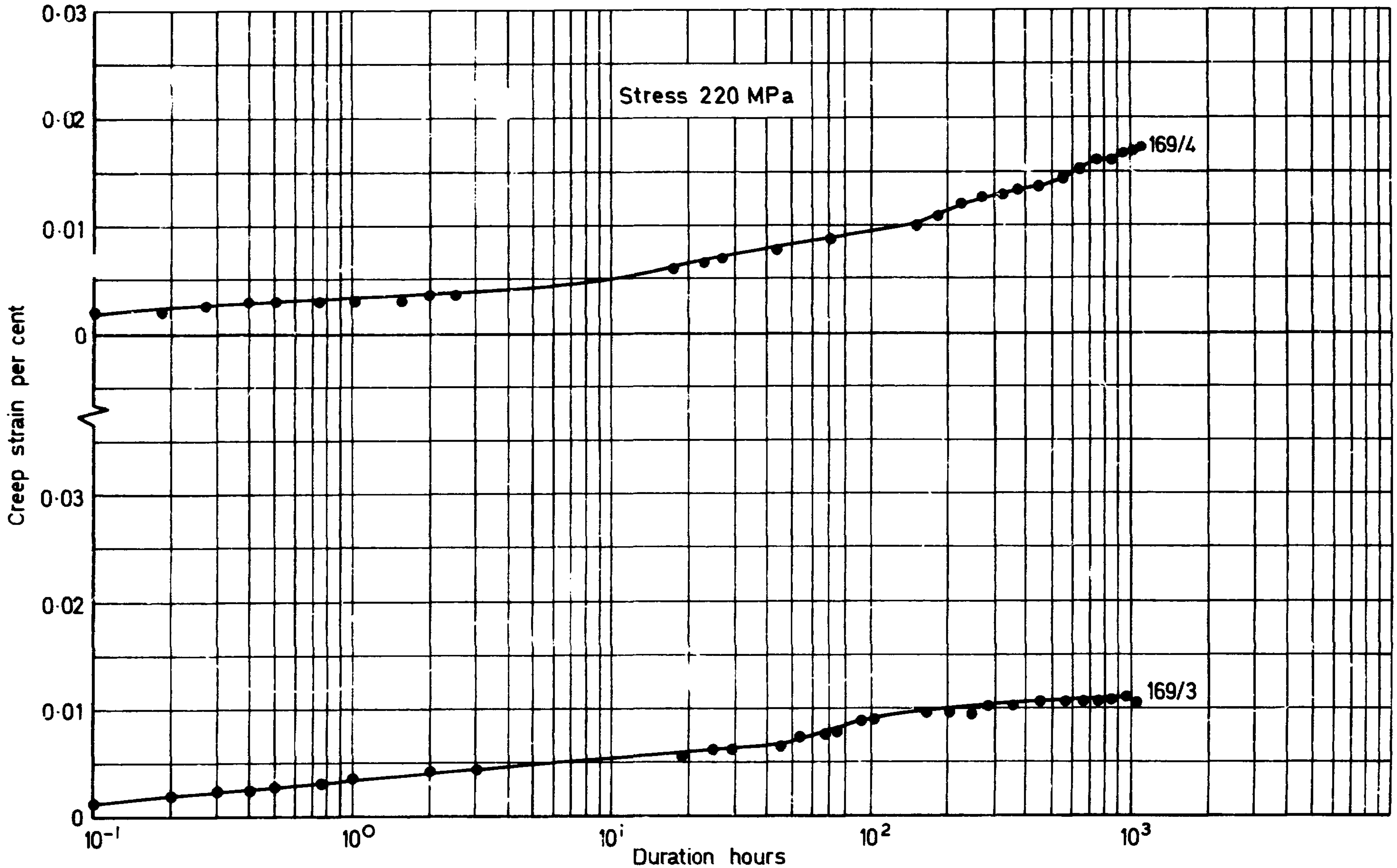

Fig. 9 Results of creep tests at 21°C on cross-plied 0 + 90° CFRP

Fig.10

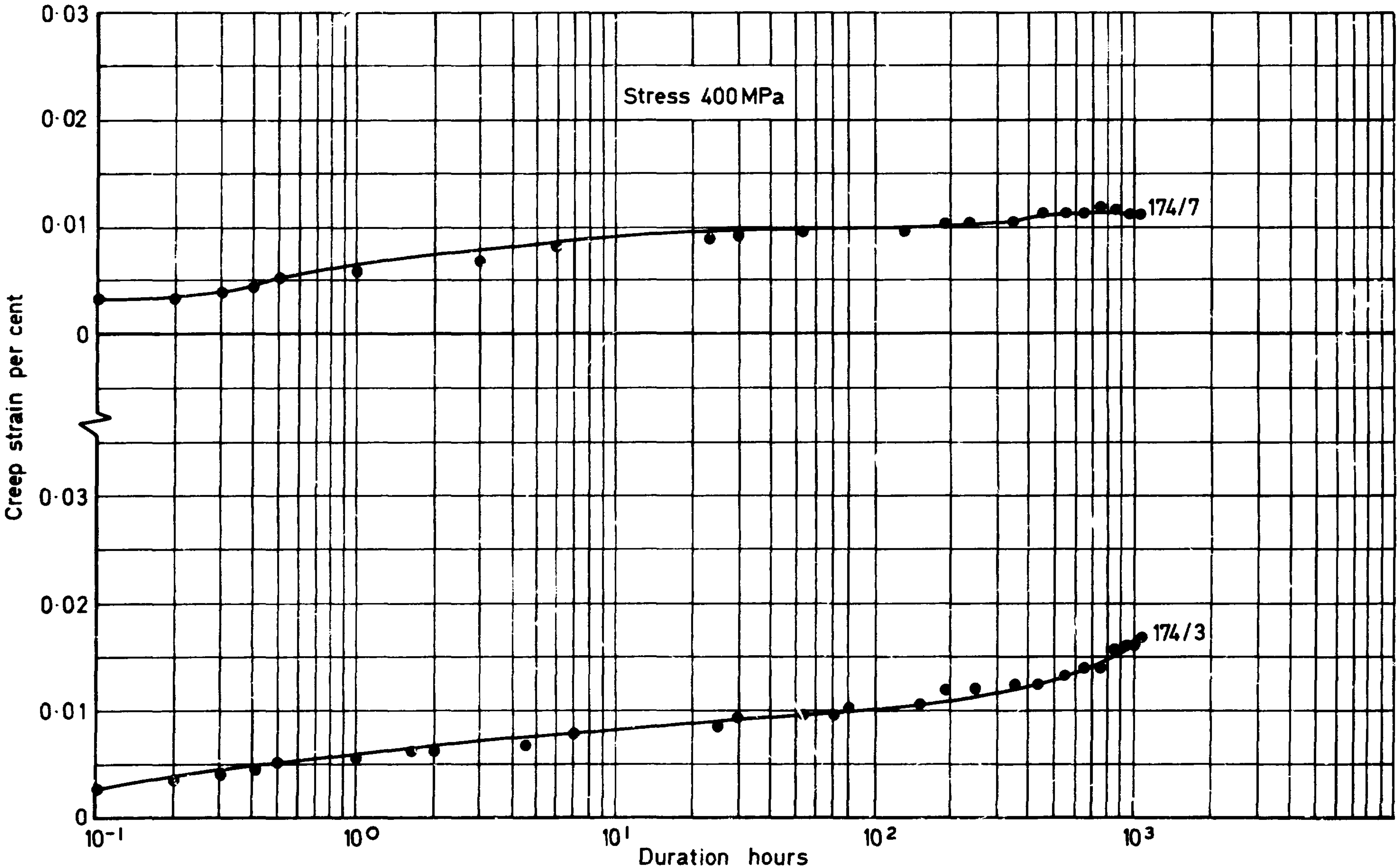

Fig. 10 Results of creep tests at 21°C on cross-plied 0 + 90° CFRP

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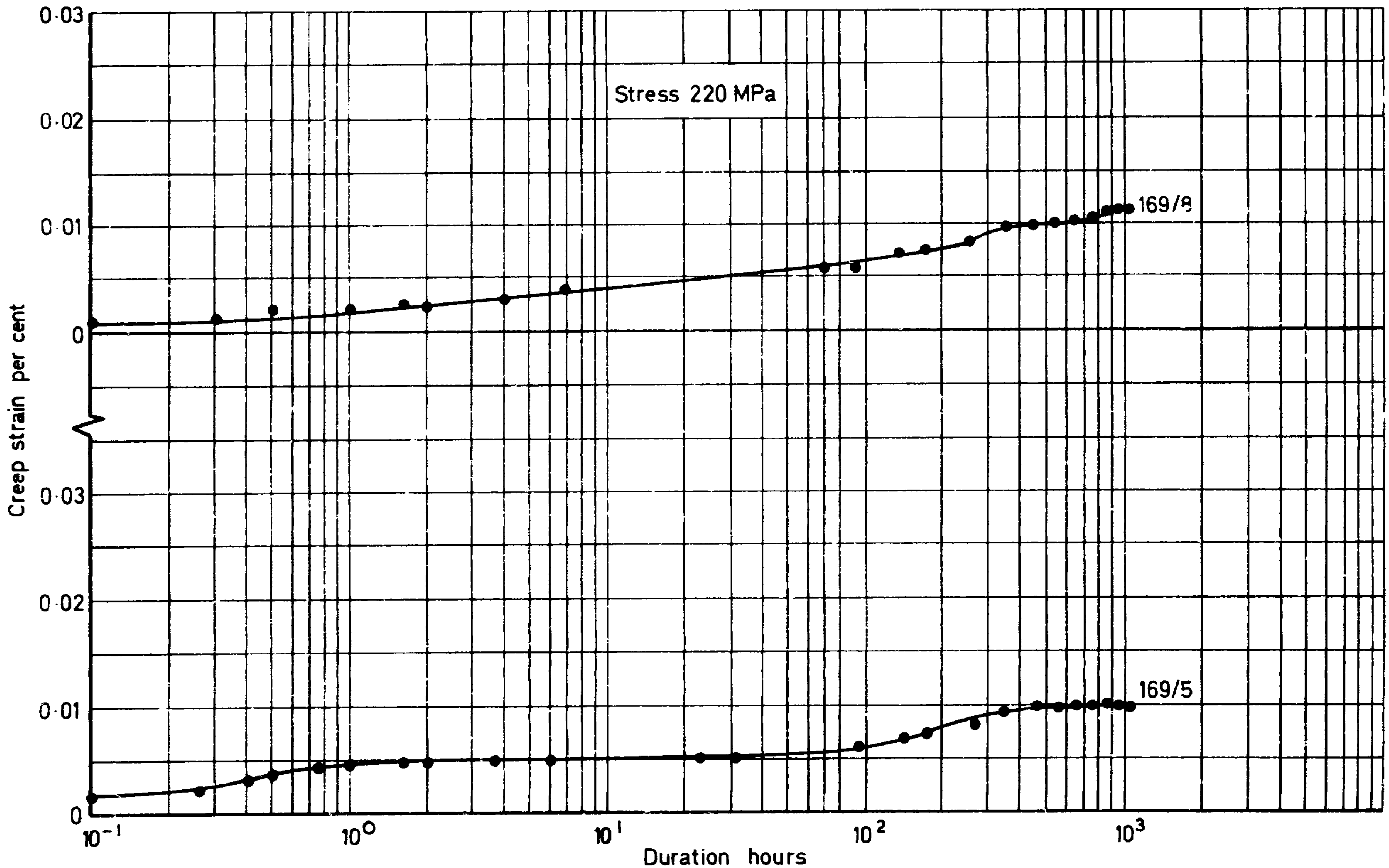

Fig. 11 Results of creep tests at 80°C on cross-plied 0 + 90° CFRP

Fig.12

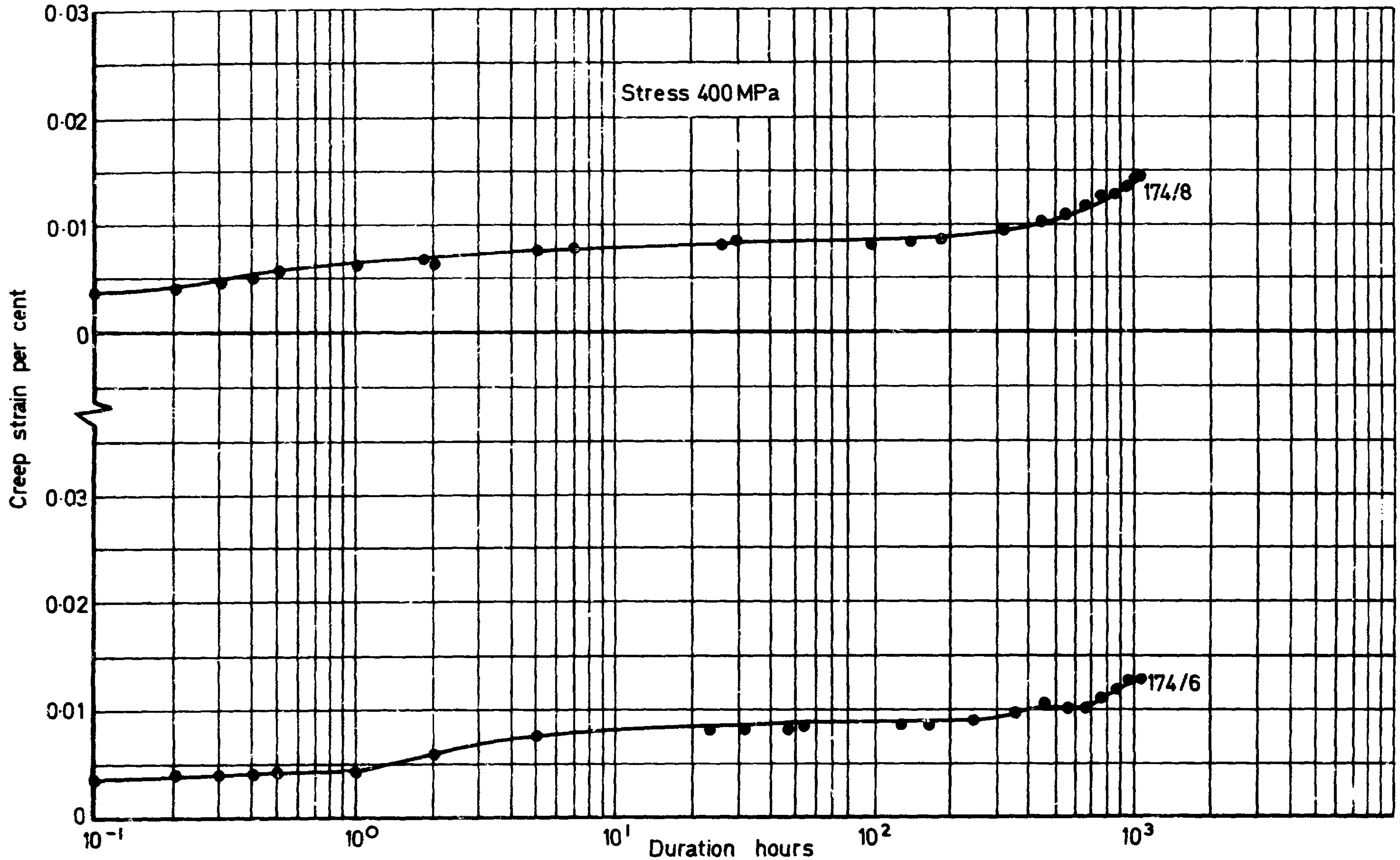

Fig.12 Results of creep tests at 80°C on cross-plied 0 + 90° CFRP

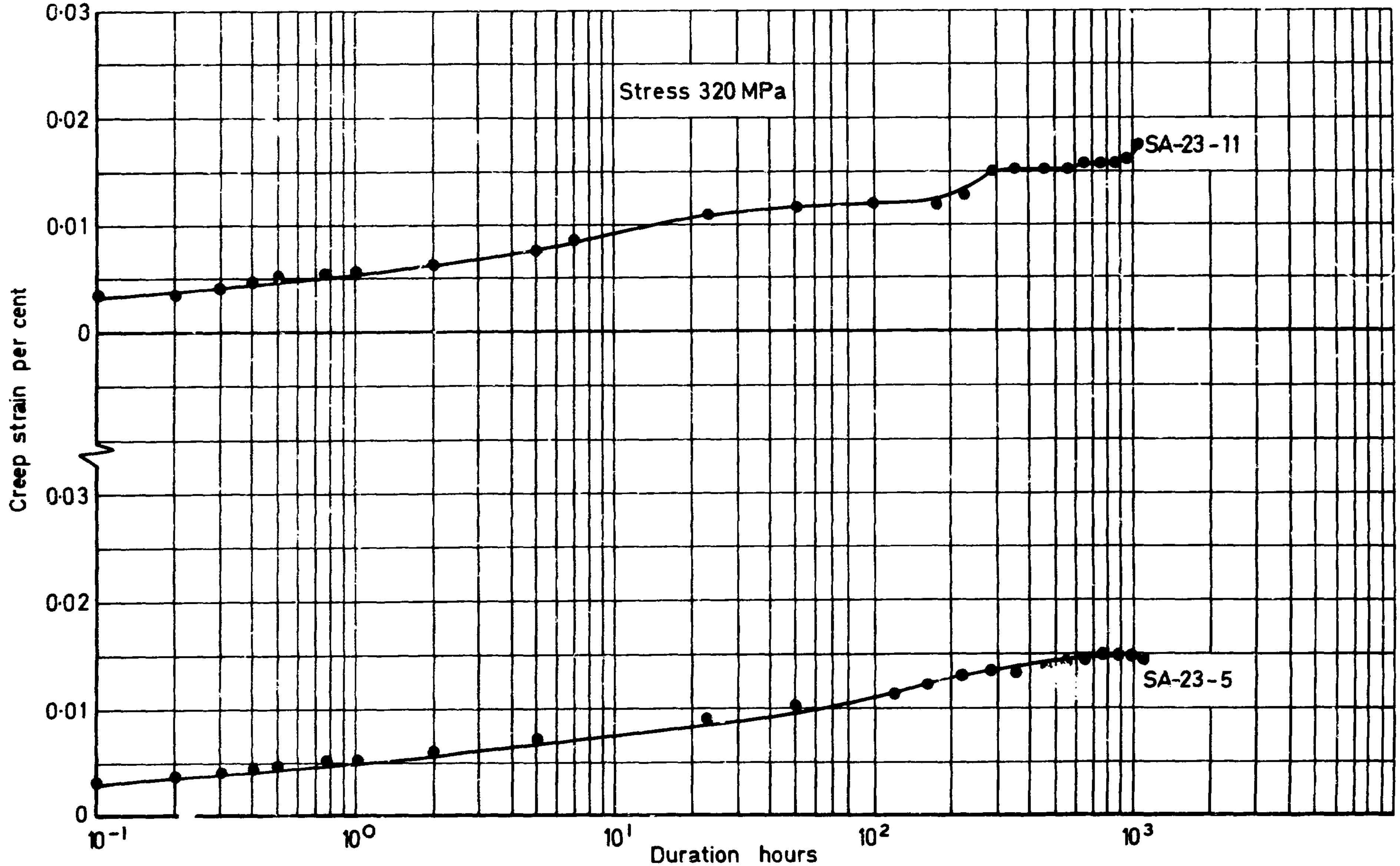

Fig. 13 Results of creep tests at 21°C on multi-plied 0±45°CFRP

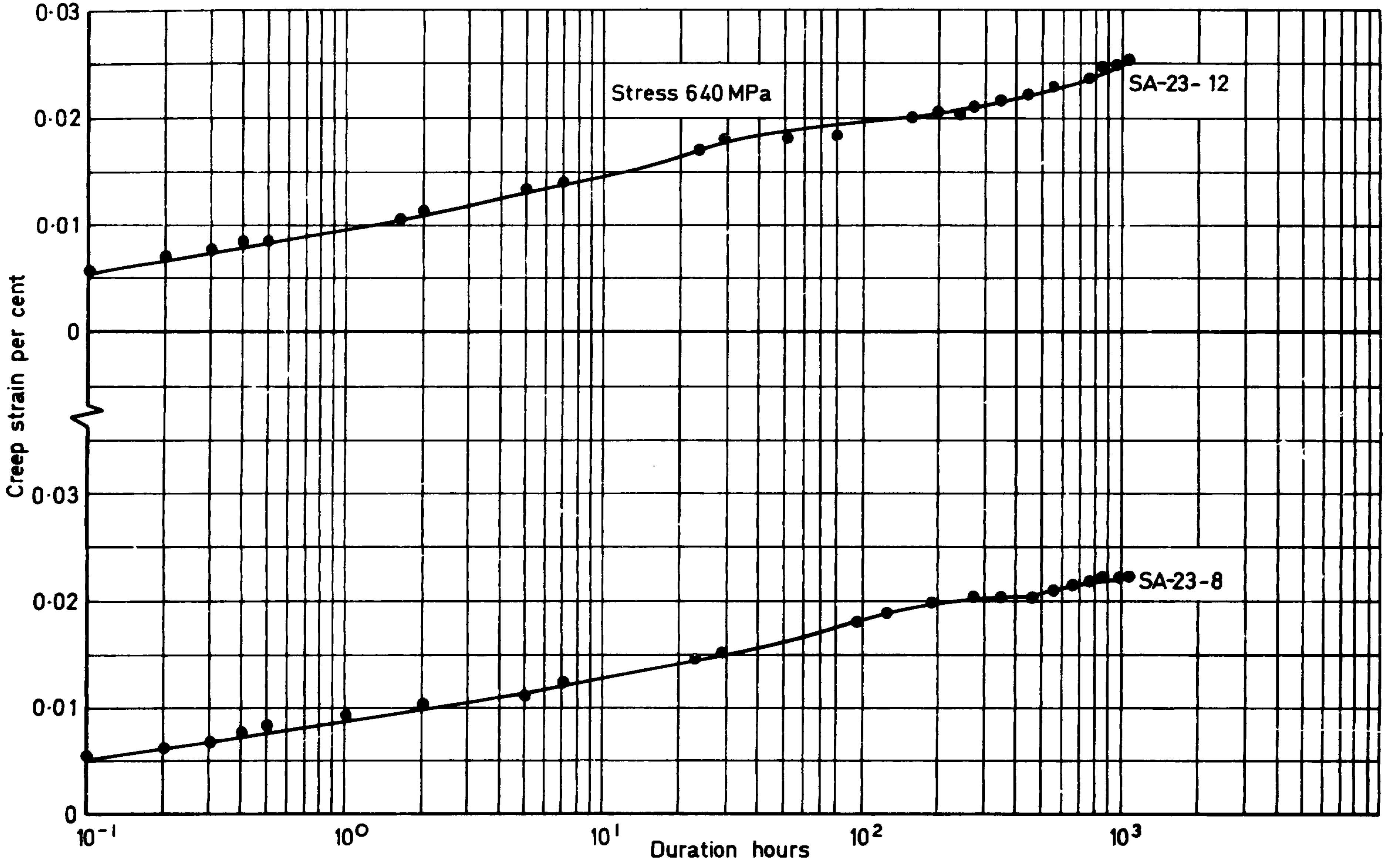

Fig. 14 Results of creep tests at 21°C on multi-plied 0±45° CFRP

TR 76168

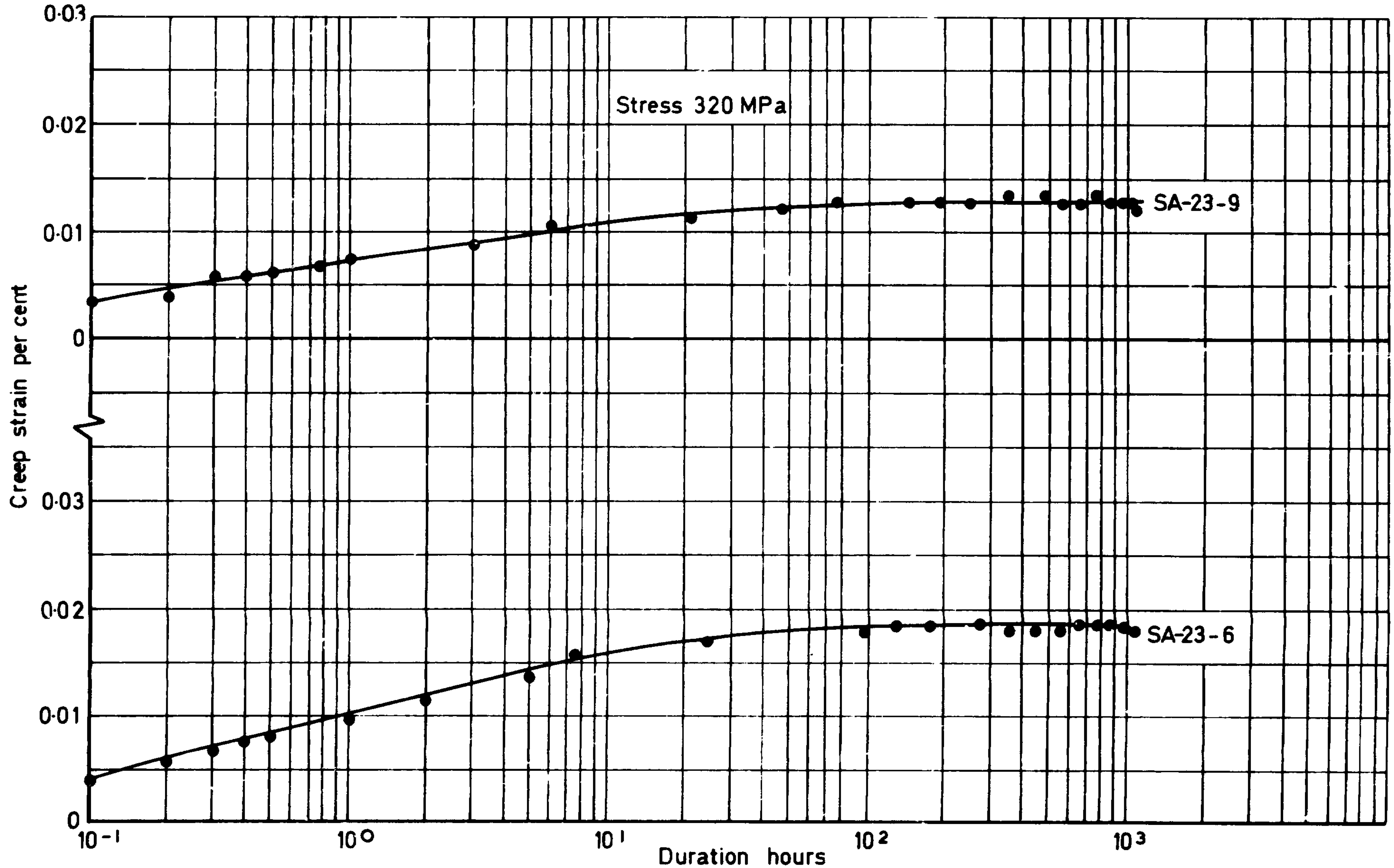

Fig.15 Results of creep tests at 80°C on multi-plied 0±45° CFRP

Fig.16

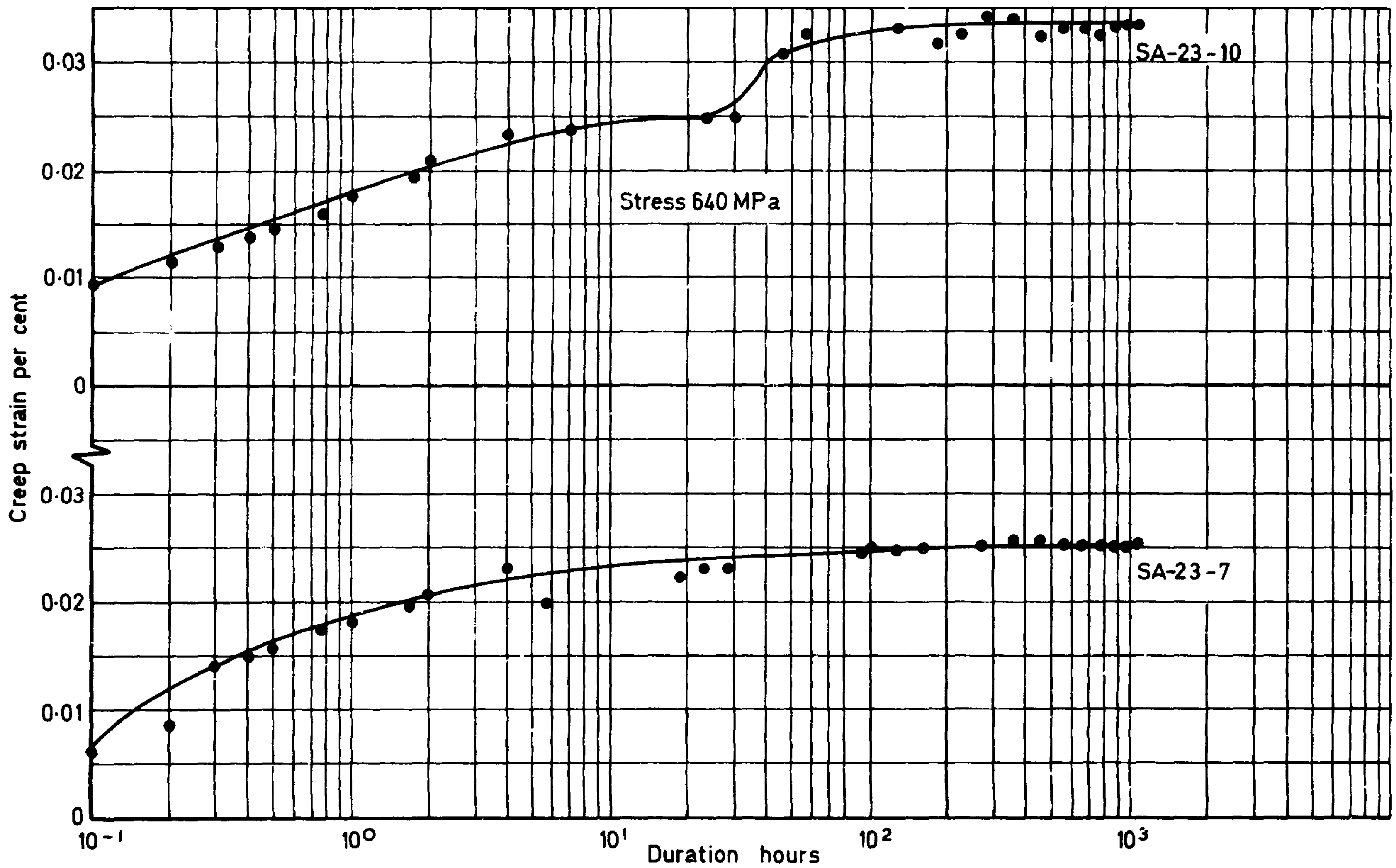

Fig.16 Results of creep tests at 80°C on multi-plied 0±45°CFRP

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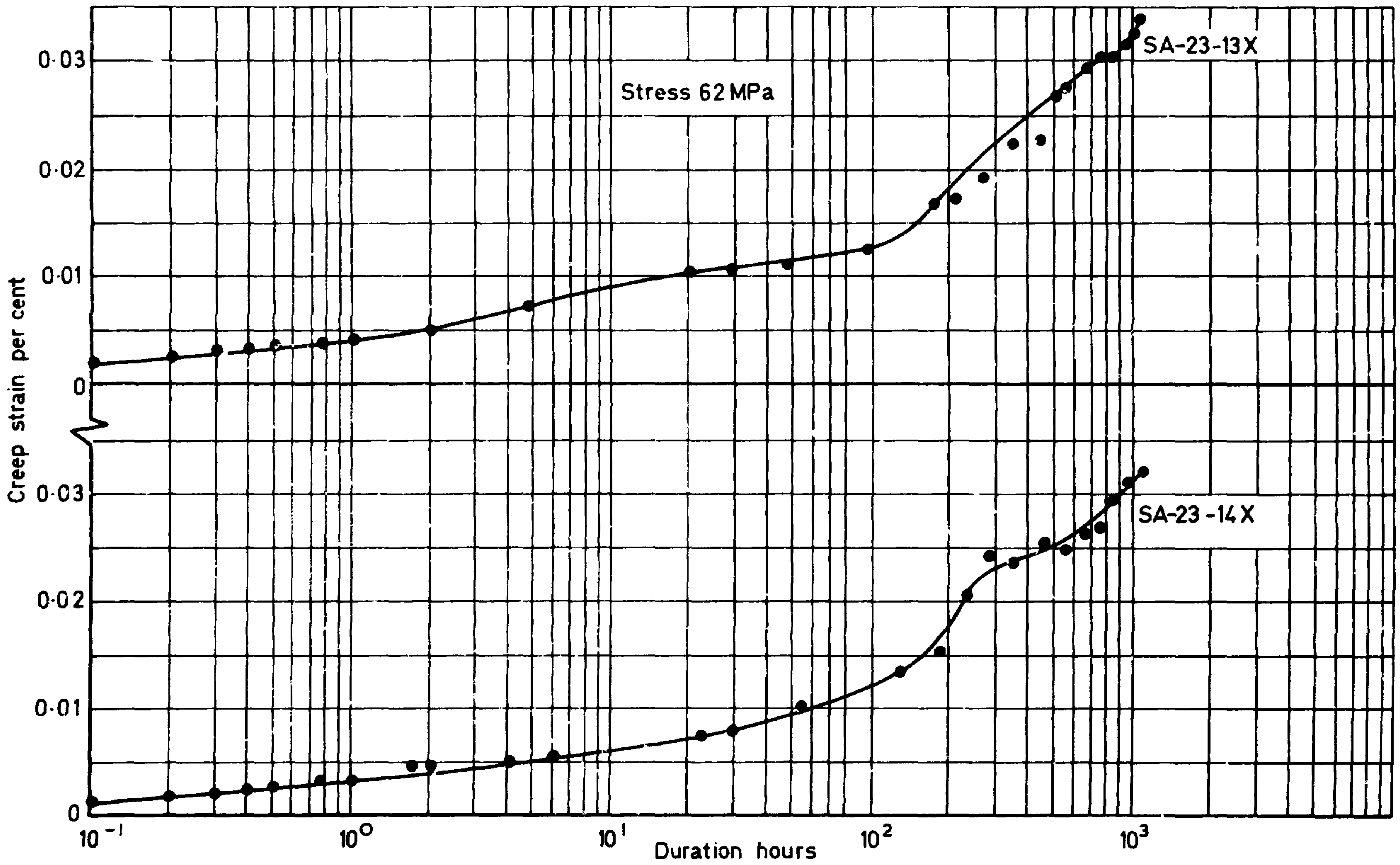

Fig.17 Results of creep tests at 21°C on multi-plied 90±45° CFRP

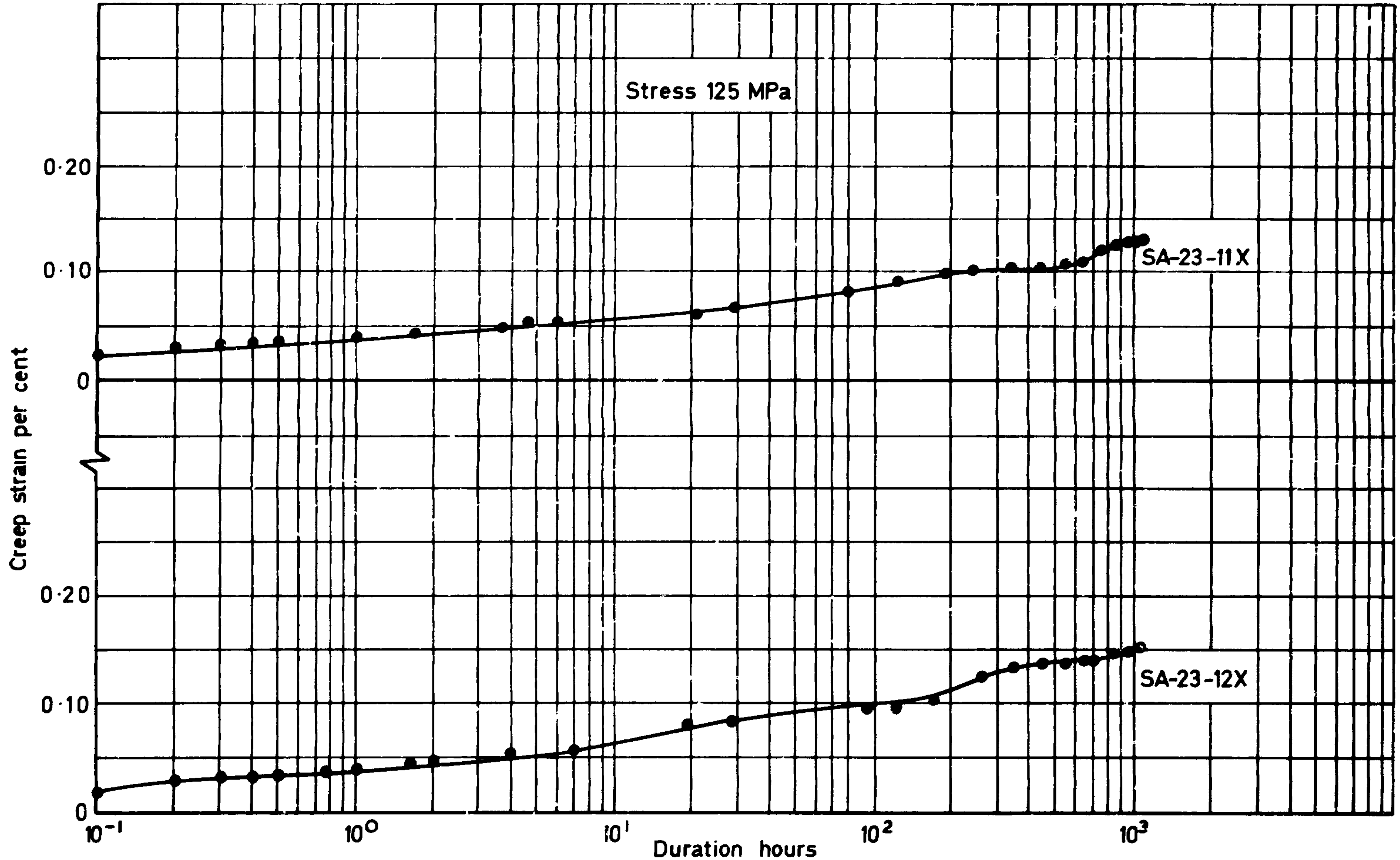

Fig. 18 Results of creep tests at 21°C on multi-plied 90±45°CFRP

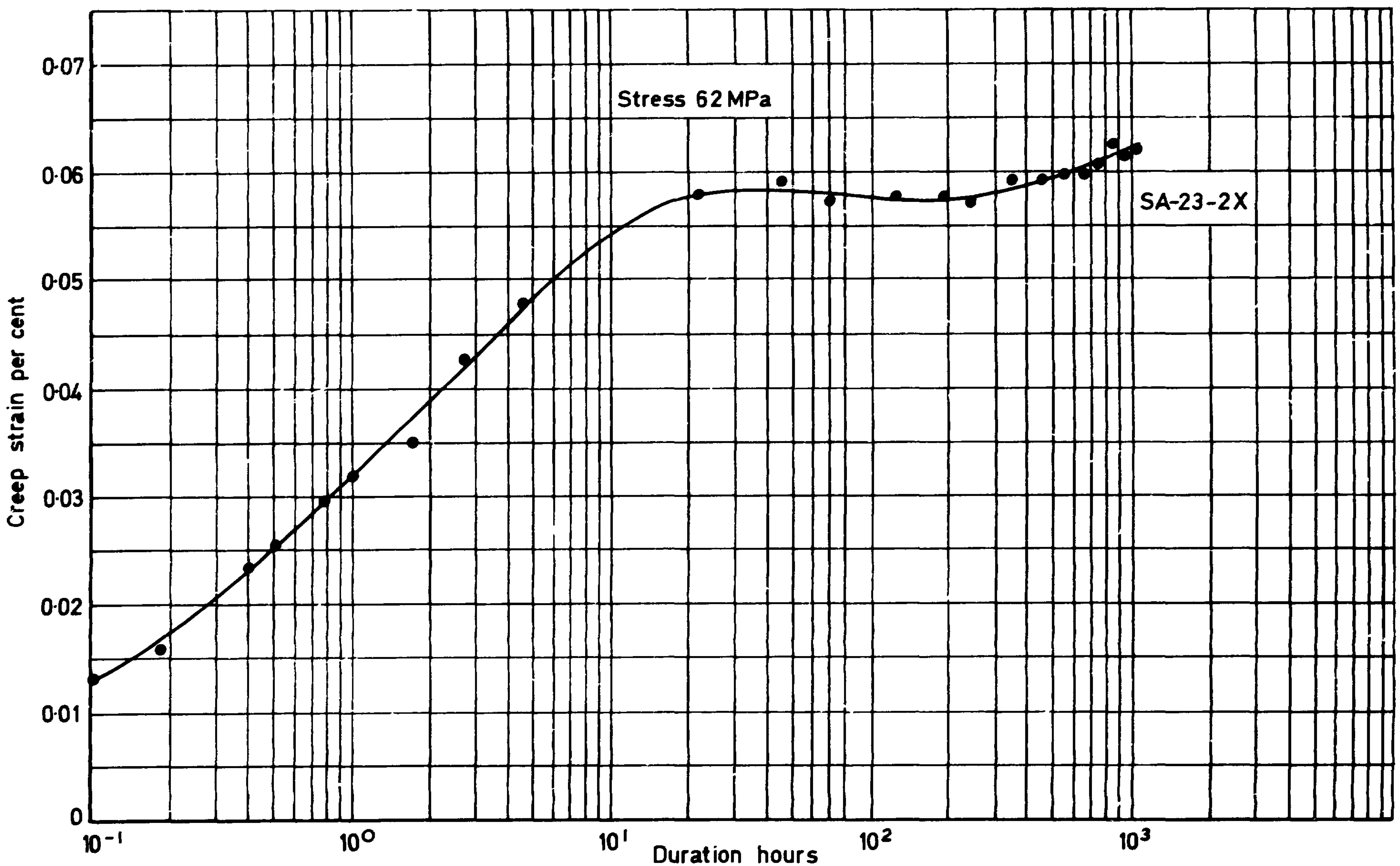

Fig.19a Results of a creep test at 80°C on multi-plied 90±45° CFRP

Fig.19b

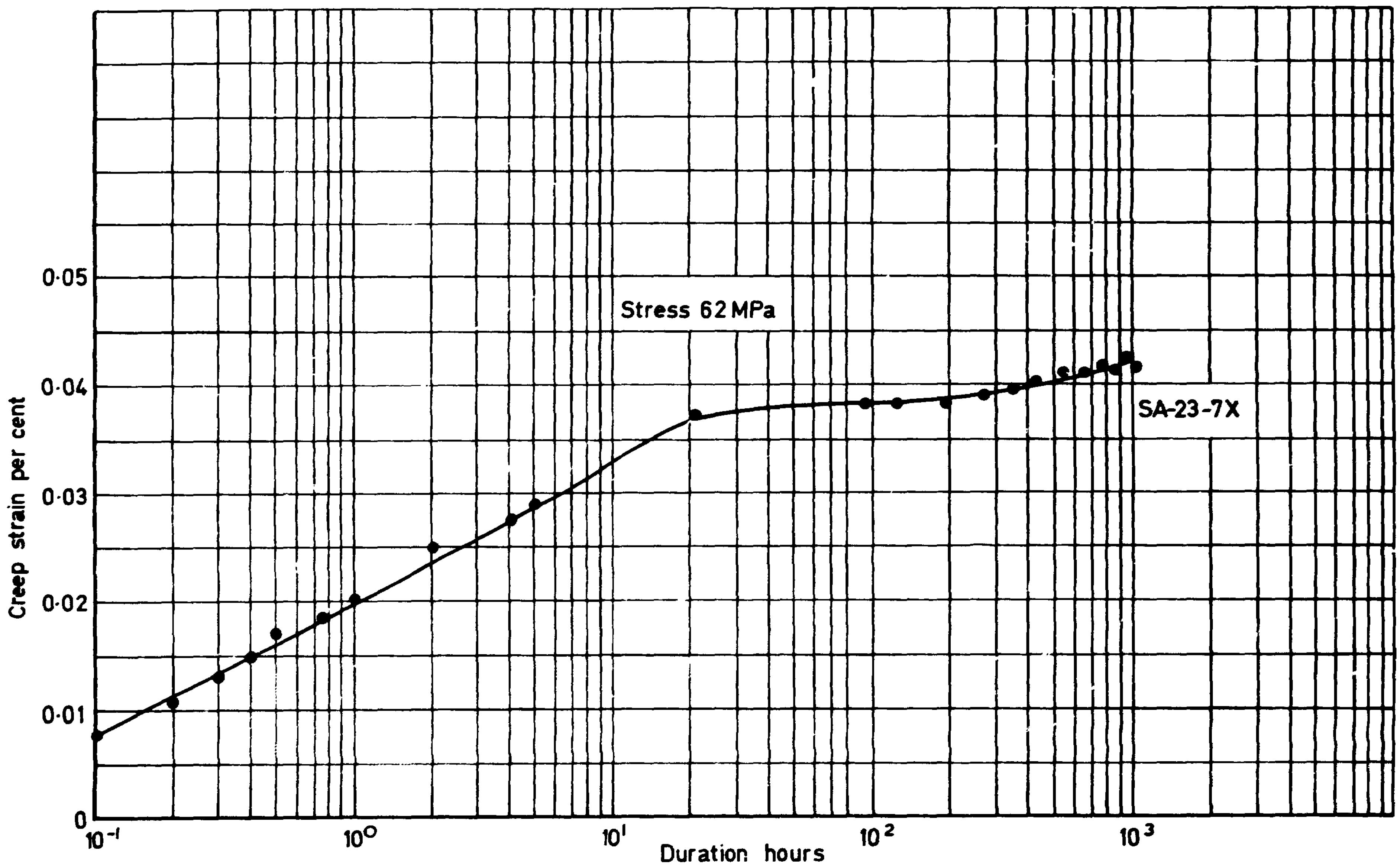

Fig 19 b Results of creep test at 80°C on multi-plied 90 ± 45° CFRP

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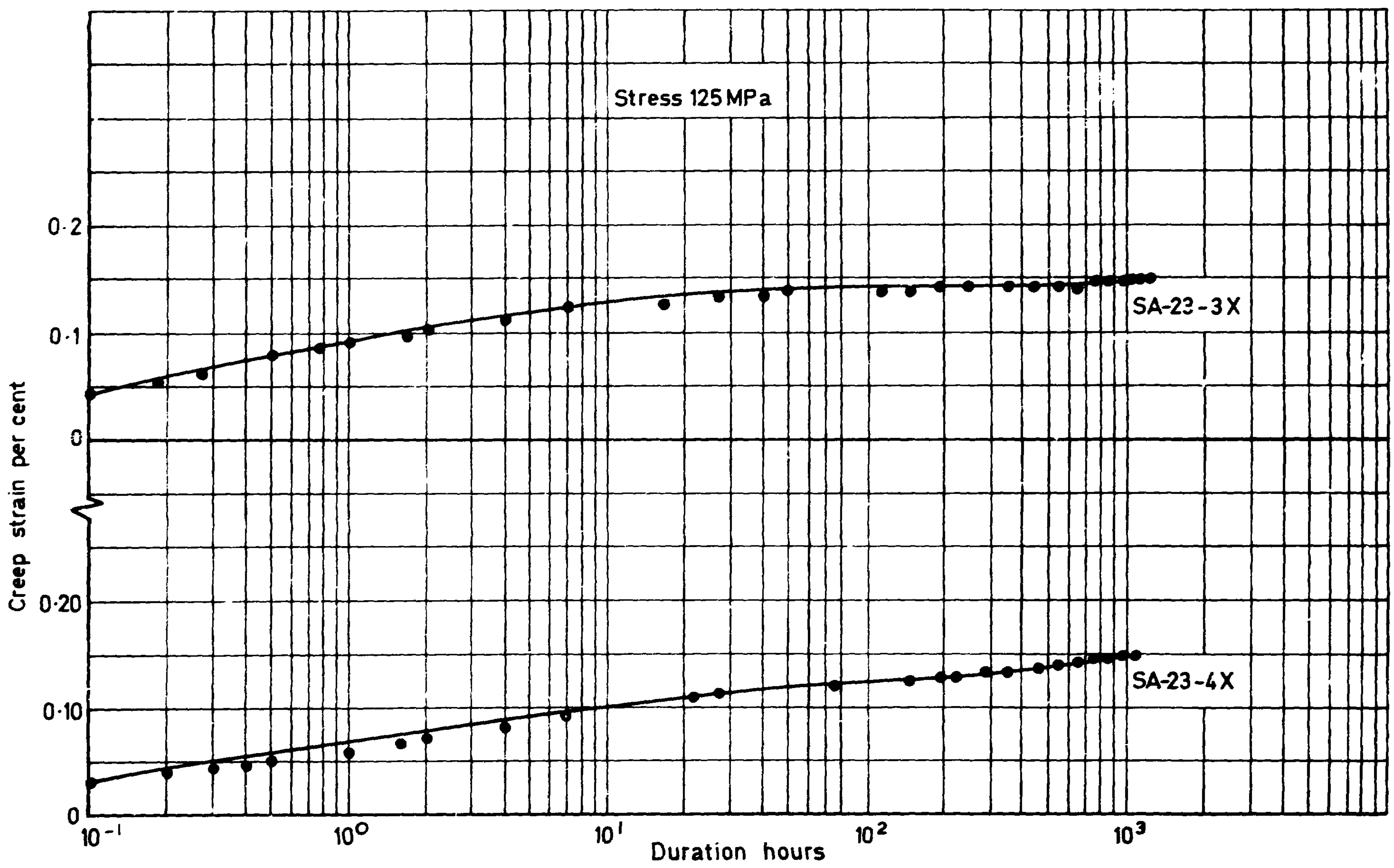

Fig.20 Results of creep tests at 80°C on multi-plied 90±45°CFRP

Fig.21

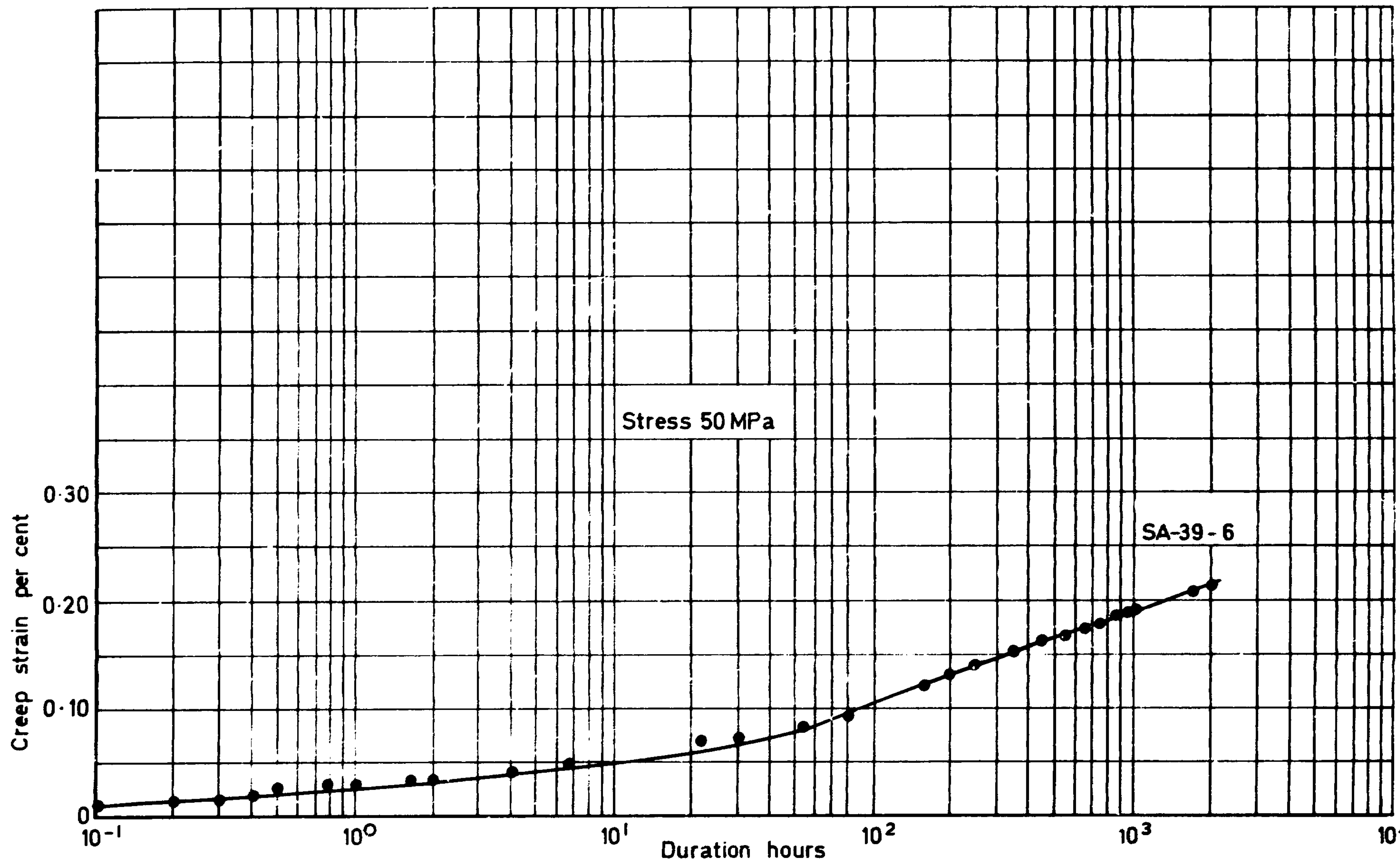

Fig. 21 Results of creep test at 21°C on angle-plied ± 45° CFRP

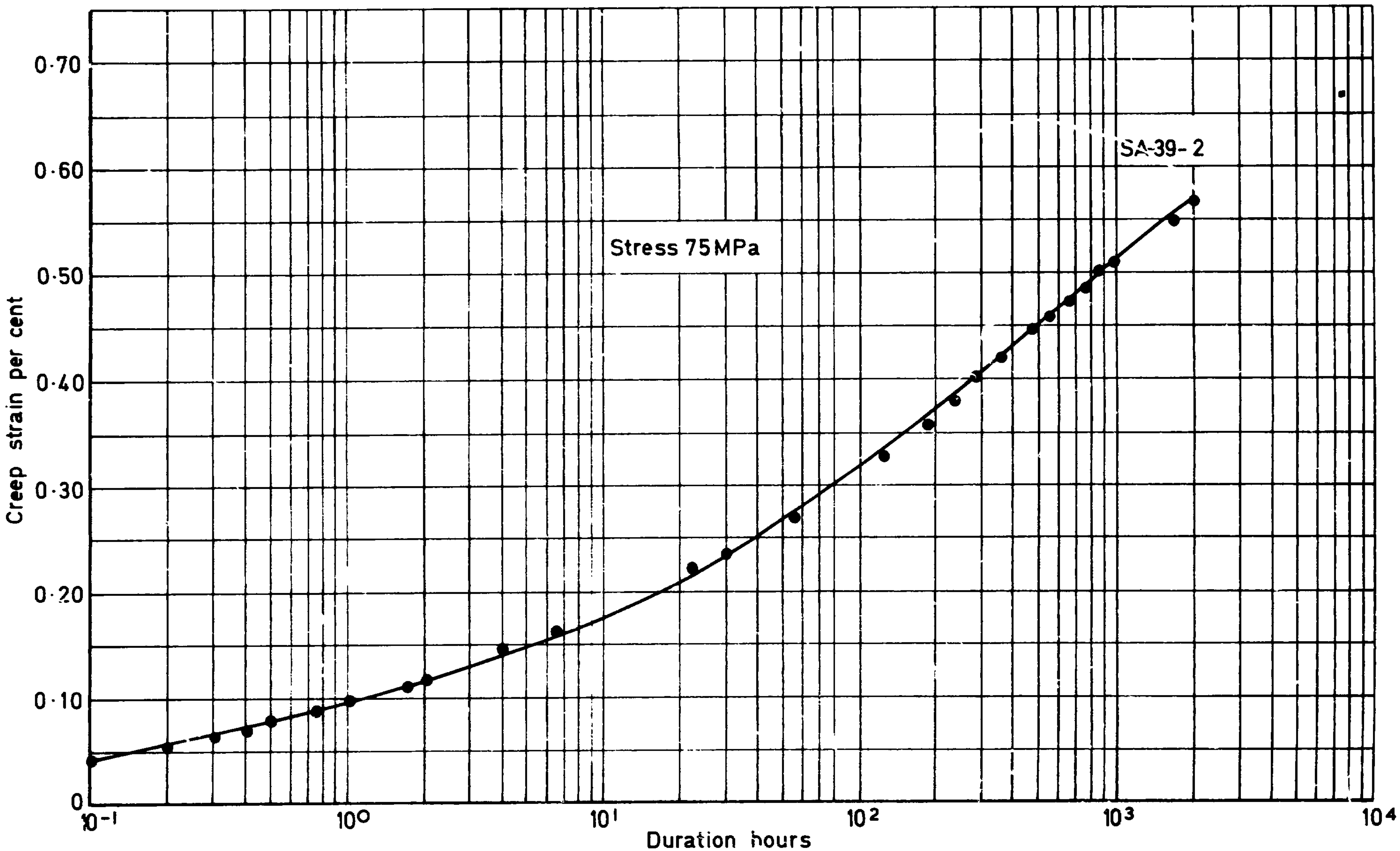

Fig. 22 Results of creep test at 21°C on angle-plied ± 45° CFRP

Fig. 22

Fig.23

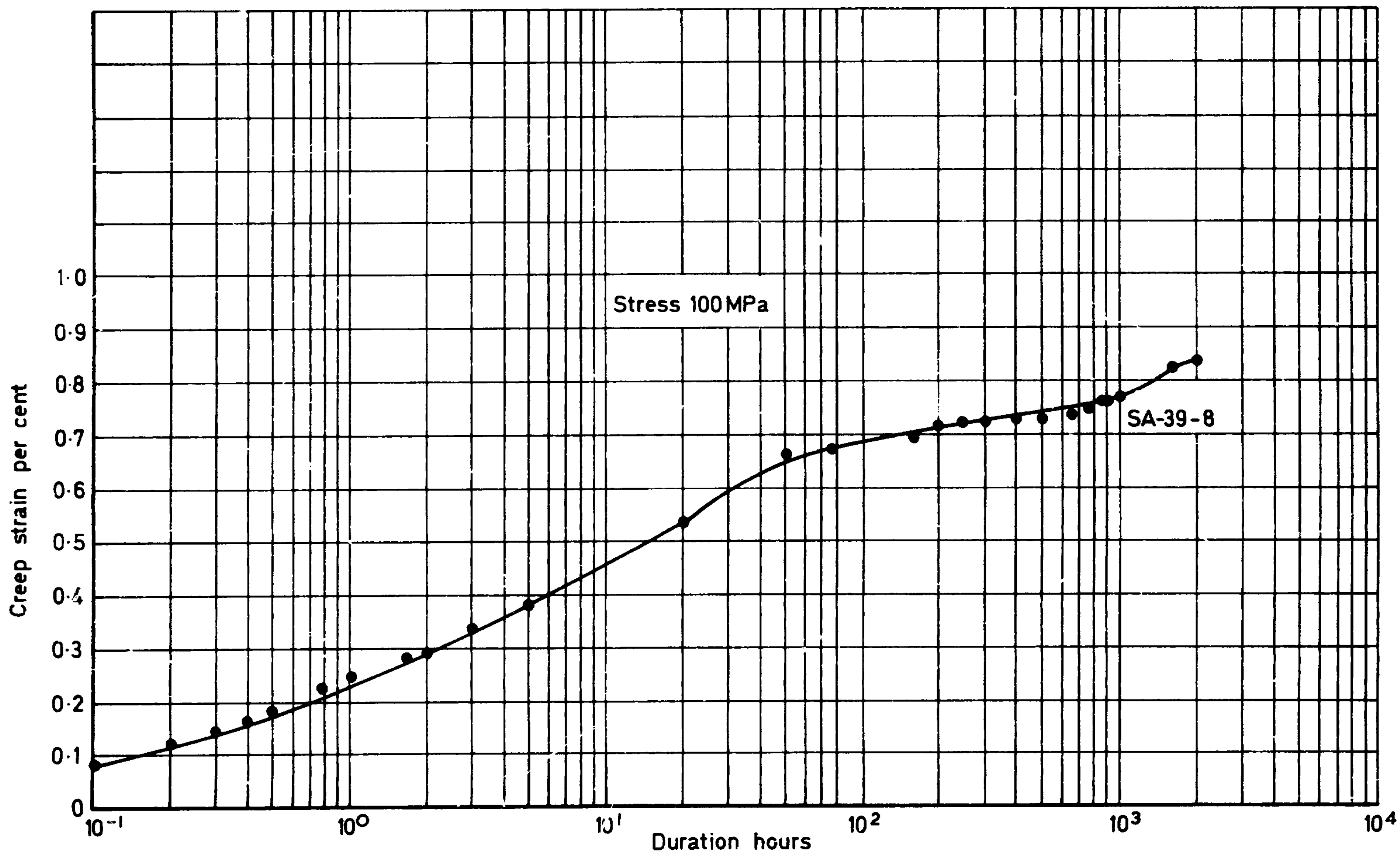

Fig.23 Results of creep test at 21°C on angle-plied ± 45° CFRP

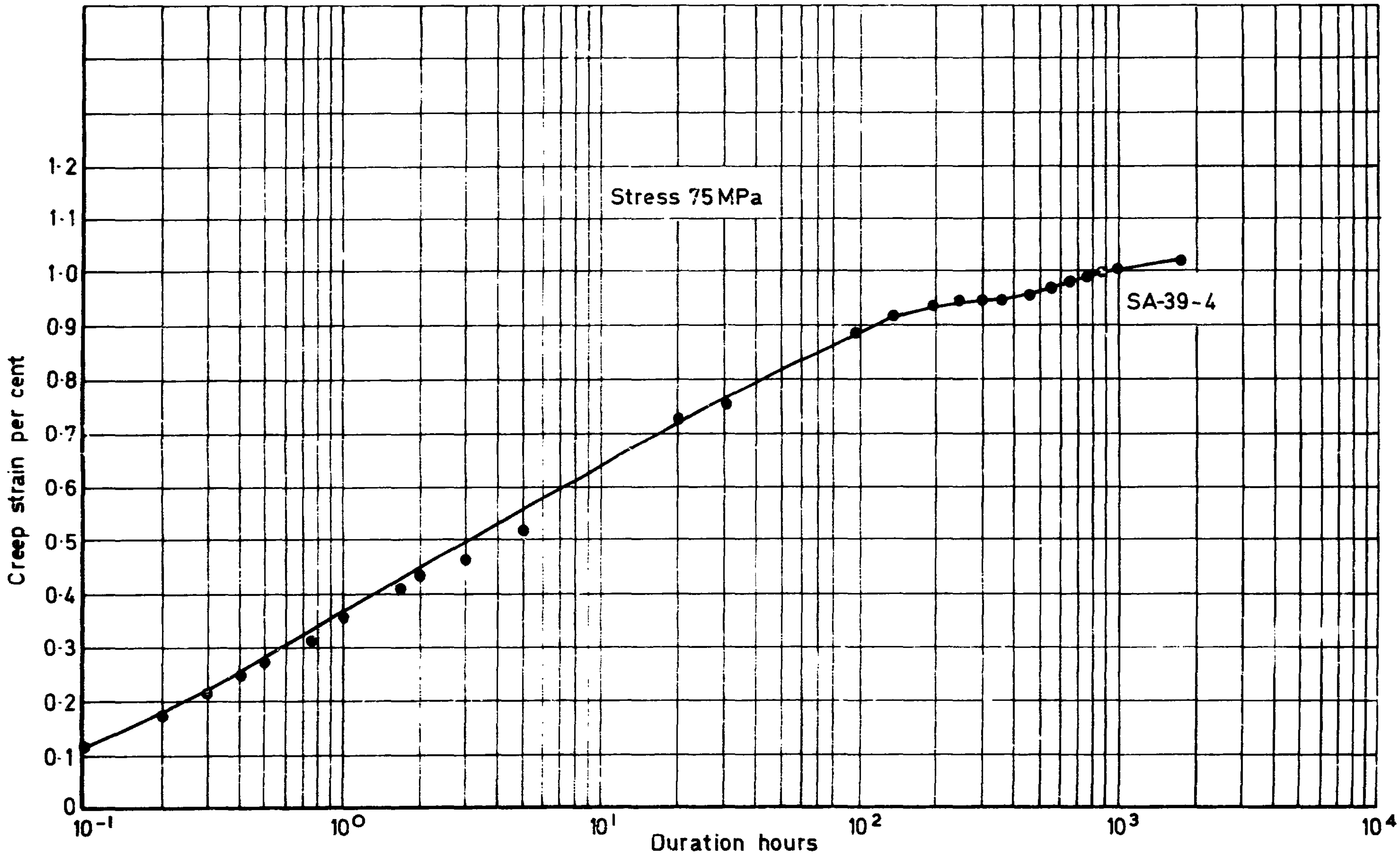

Fig.24 Results of creep test at 50°C on angle-plied ± 45° CFRP

Fig.25

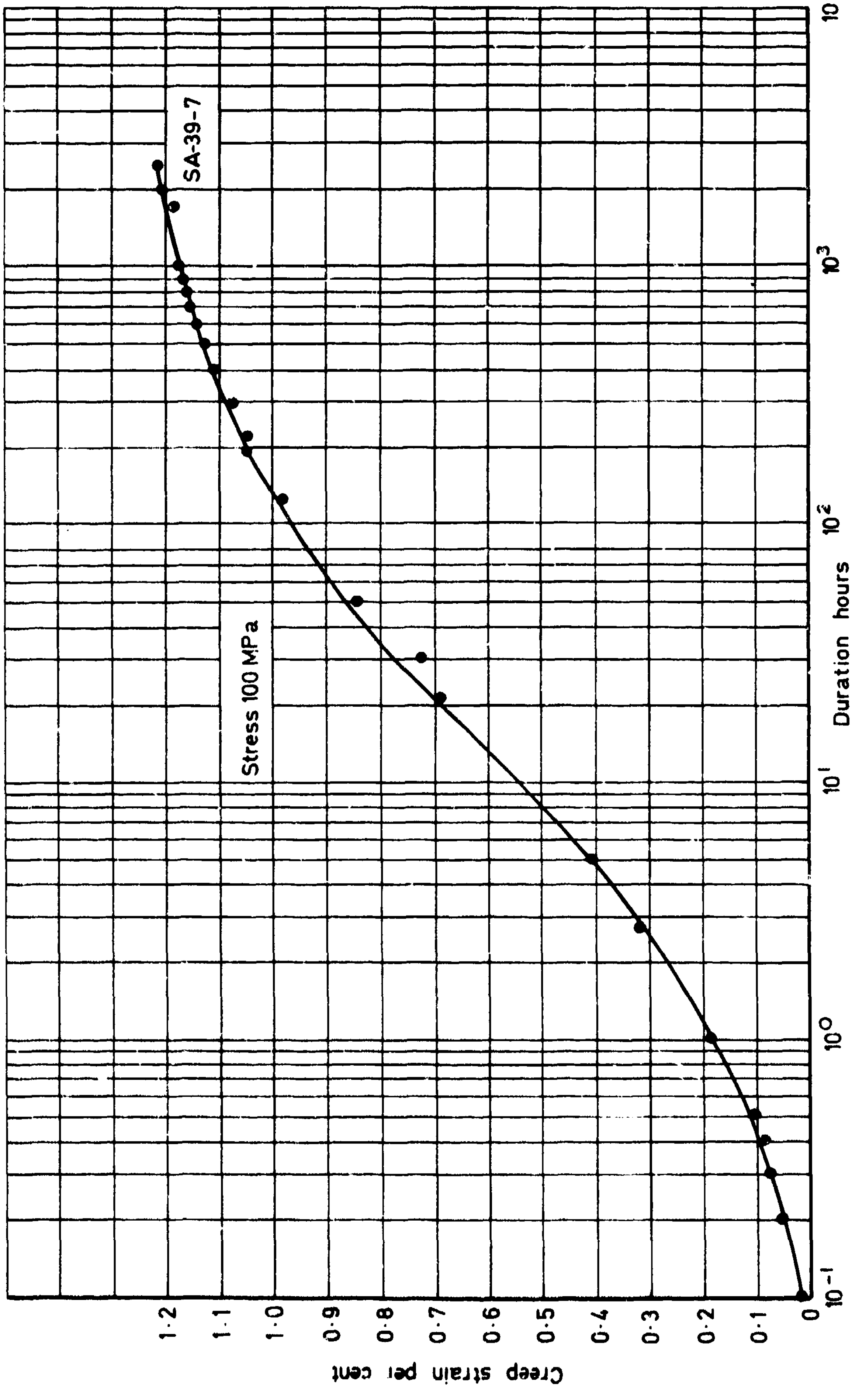

Fig.25 Results of a creep test at 50°C on angle-plied ± 45°CFRP

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

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850100	Royal Aircraft Establishment, Farnborough, Hants, UK
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7\. Title Creep of carbon fibre reinforced plastics

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7b. (For Conference Papers) Title, Place and Date of Conference

Institute of Physics Conference 'Time dependent stresses and strains in plastics materials'. 2 November 1976. Cranfield Institute of Technology, Cranfield, Bedford, UK

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Sturgeon, J.B.	Butt, R.I.	Larke, L.W.	December 1976	43	6
11. Contract Number	**12. Period**	**13. Project**	**14. Other Reference Nos.**		
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15\. Distribution statement

(a) Controlled by – Unlimited

(b) Special limitations (if any) –

16\. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Carbon fibre reinforced epoxy resin. Creep tests. Unidirectional. Angle-plied. Multi-plied composite.

17\. Abstract

Creep tests have been performed on unidirectional 0°, cross-plied 0 + 90°, angle-plied ±45° and multi-plied 0 ± 45° and 90 ± 45° carbon fibre reinforced plastics. The test temperatures were 20°C and 80°C except for ±45° orientations where the upper temperature was 50°C.

Small creep strains were observed in 0°, 0 + 90° and 0 ± 45° materials after 1000 hours at stresses of 40% and 70% of the tensile strength. The creep resistance of 90 ± 45° composite was lower than material containing 0° fibres but higher than simple ±45° constructions.

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